Debris/Ice/TPS Assessment and Integrated Photographic Analysis of Shuttle mission STS-105

Armando Oliu

Technical Memorandum – 2005-211537 **February 1 2005**

DEBRIS/ICE/TPS ASSESSMENT and INTEGRATED PHOTOGRAPHIC ANALYSIS OF SHUTTLE MISSION STS-105

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AND
INTEGRATED PHOTOGRAPHIC ANALYSIS
OF
SHUTTLE MISSION STS-105

August 10, 2001

Contributions By:

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FOREWORD

The Debris Team has developed and implemented measures to control damage from debris in the Shuttle operational environment and to make the control measures a part of routine launch flows. These measures include engineering surveillance during vehicle processing and closeout operations, facility and flight hardware inspections before and after launch, and photographic analysis of mission events.

Photographic analyses of mission imagery from launch, on-orbit, and landing provide significant data in verifying proper operation of systems and evaluating anomalies. In addition to the Kennedy Space Center Photo/Video Analysis, reports from Johnson Space Center and Marshall Space Flight Center are also included in this document to provide an integrated assessment of the mission.

Photo 1: Launch of Shuttle Mission STS-105

1.0 SUMMARY OF SIGNIFICANT EVENTS

STS-105 consisted of OV-103 Discovery (30th flight), ET-110, and BI-109 SRB's on MLP-3 and Pad 39A. Discovery was launched at 5:10:14 EDT on 10 August 2001. Landing was at 2:23 p.m. local/eastern time on 22 August 2001.

Post landing inspection of Orbiter tiles showed a total of 144 hits, of which 25 had a major dimension of 1-inch or larger. The Orbiter lower surface sustained 108 total hits, of which 15 had a major dimension of 1-inch or larger, both numbers are within family. The majority of the hits (57 total with 11 greater than 1-inch) were located in the area from the nose landing gear to the main landing gear wheel wells on both left and right chines. The pattern and size ratio of these hits is indicative of damage from ET foam loss. This is the highest number of hits in this area since the implementation of ET intertank foam venting.

In summary, both the total number of Orbiter TPS debris hits and the number of hits 1-inch or larger were somewhat less than the family average. ET TPS venting modifications continue to have a reducing effect on the quantity and size of the damage sites

2.0 PRE-LAUNCH BRIEFING

The Debris/Ice/TPS and Photographic Analysis Team briefing for launch activities was conducted at 1500 on 8 August 2001. The following personnel participated in various team activities, assisted in the collection and evaluation of data, and contributed to reports contained in this document.

A.Oliu	NASA - KSC	Shuttle Ice/Debris Systems
J. Rivera	NASA - KSC	ET Mechanisms/Structures
R. Speece	NASA - KSC	ET Thermal Protection Systems
B. Nguyen	NASA - KSC	SRB Mechanical Systems
M. Payne	NASA - KSC	SRB Mechanical Systems
R. Page	NASA - KSC	SSP Integration
K. Leggett	USA - SFOC	Supervisor, ET/SRB Mechanical Systems
J. Blue	USA - SFOC	ET Mechanical Systems
W. Richards	USA - SFOC	ET Mechanical Systems
M. Wollam	USA - SFOC	ET Mechanical Systems
T. Ford	USA - SFOC	ET Mechanical Systems
R. Seale	USA - SFOC	ET Mechanical Systems
R. Brewer	USA - SFOC	ET Mechanical Systems
R. Oyer	Boeing	Systems Integration
D. Leggett	Boeing	Systems Integration
B. Atkinson	Boeing	Systems Integration
T. Wilson	Boeing	Systems Integration
S. Otto	LMMSS	ET Processing
J. Ramirez	LMMSS	ET Processing
A. Khodaoust	Boeing	Shuttle Aerodynamics
M. Eastwood	Thiokol-LSS	SRM Processing

2.1 PRE-LAUNCH SSV/PAD DEBRIS INSPECTION

The pre-launch inspection of the MLP-3, Pad A FSS and RSS was conducted on 8 August 2001 from 1600 to 1830 hrs EDT. No flight hardware issues/anomalies were detected.

No facility items were documented in Appendix K of S0007VL4. Minor clean-up items were in-work.

The west OWP corrugated sheeting was missing a fastener head on the groove wedge. This was documented on a facility PR (PV-6-377725). However, Debris Team expressed concern that wedge may not be held in place by remaining fastener portion. The decision was made to secure wedge with another fastener. This item was in-work at the conclusion of the Debris Inspection.

Additional Pad work, including preparations for RSS rollback, were in-work at the conclusion of the Debris Inspection.

Photo 2: Missing fastener on OWP

Facility PR (PV-6-377725) was picked up to document the missing a fastener head on the groove wedge.

3.0 SCRUB

3.1 FINAL INSPECTION – Weather Scrub

The Final Inspection of the cryoloaded vehicle was performed from 1130 to 1300 hrs on 9 August 2001 during the two-hour built-in-hold at T-3 hours in the countdown. There were no Launch Commit Criteria (LCC) or OMRS criteria violations. There was no acreage icing concerns. There was also no protuberance icing conditions outside of the established database.

A portable Shuttle Thermal Imager (STI) infrared scanning radiometer was utilized to obtain vehicle surface temperature measurements for an overall thermal assessment of the vehicle, particularly those areas not visible from remote fixed scanners, and to scan for unusual temperature gradients.

3.1.1 ORBITER

No Orbiter tile or RCC panel anomalies were observed. The RCS thruster paper covers were intact with none discolored. Ice/frost had formed all the way around the SSME #2 heat shield-to-nozzle interface and from the 6 to 9 o'clock position around the SSME #1 heat shield-to-nozzle interface.

3.1.2 SOLID ROCKET BOOSTERS

No SRB case, closeout, or protuberance anomalies were observed. SRB case temperatures measured by the STI radiometers were close to ambient temperatures, ranging from 80 to 88 degrees F. All measured temperatures were above the minimum requirement.

3.1.3 EXTERNAL TANK

The ice/frost prediction computer program 'SURFICE' was run as a comparison to infrared scanner point measurements. The program predicted temperatures above the 32 degrees F throughout ET cryoload. The following table shows ambient condition, SURFICE prediction and IR surface temperatures at the start of FIT walkdown. The difference between the predicted SURFICE temperatures and the IR surface readings can be attributed to the fact that there was a significant amount of sunlight striking the surface of the external tank during the inspection. The SURFICE Ice Prediction Program does not take into account the effect the sun has on the ET surface temperatures.

Ambient conditions – 1100hrs	SURFICE Predictions	IR Surface Readings
83 Degrees F.	LO2 ogive 69 Degrees F	LO2 Tank 75-92 Degrees F
76% RH	LO2 barrel 66 Degrees F	
7 knots	LH2 upper 67 Degrees F	LH2 Tank 82-92 Degrees F
035 degrees	LH2 lower 71 Degrees F	

The Final Inspection Team observed very light condensation on the LO2 tank acreage. No acreage ice/frost formations were observed. There were no TPS anomalies.

No significant anomalies were present in the intertank TPS. No cracks were observed in the intertank stringer valley TPS. Ice and frost accumulations on the GUCP were typical.

The LH2 tank was wet with light condensate on the upper portion and significantly more condensation at the aft end. There were no acreage TPS anomalies.

Typical amounts of ice/frost had accumulated in the LO2 feedline bellows and support brackets.

A 4 inch long and 1/8 inch wide stress relief crack was observed in the –Y vertical strut TPS with no offset. This condition has been observed on previous vehicles and found acceptable for flight per the NSTS-08303 criteria.

There were no TPS anomalies on the LO2 ET/ORB umbilical. Ice and frost in the LH2 recirculation line bellows and on both burst disks was typical. Likewise, a typical amount of ice/frost had accumulated on the LH2 ET/ORB umbilical purge barrier outboard side, forward, and aft surfaces. Typical ice/frost fingers were present on the pyro canister and plate gap purge vents. No unusual vapors or cryogenic drips had appeared during tanking, stable replenish, and launch.

3.1.4 FACILITY

All SRB sound suppression water troughs were filled and properly configured for launch. No leaks were observed on the GUCP or the LO2 and LH2 Orbiter T-0 umbilicals.

3.2 T-3 HOURS TO SCRUB

After completion of the Final Inspection on the pad, surveillance continued from the Launch Control Center. Twenty-two remote-controlled television cameras and two infrared radiometers were utilized to perform scans of the vehicle. No anomalies were detected during this timeframe.

This attempt to launch STS-105 was scrubbed due to inclement weather in the launch area.

3.3 POST DRAIN INSPECTION

The post drain inspection of STS-105, MLP-3, and Pad A FSS was conducted on August 9, 2001 from 2200 to 2300 hours under dark conditions. Nevertheless, visibility was adequate for the inspection.

No MLP deck or facility anomalies were detected.

Likewise, no anomalies were observed on the SRB's.

Orbiter tiles, RCC panels, and SSME's were in nominal configuration. RCS thruster paper covers were intact.

The GOX vent arm was in the retracted position. OTV monitoring from LCC Firing Room 2 was performed prior to and during GVA retraction and had verified no anomalies with the vent system or the ET nose cone and forward LO2 tank TPS. The post detank Pad inspection also verified no anomalies in this area. No topcoat was missing from the nose cone area under the GOX vent seal footprint.

The External Tank was in excellent condition. Bipod jack pad standoff closeouts were in nominal condition. All PDL repairs were intact with none protruding. No crushed foam or debris was detected in the LO2 feedline support brackets. The stress relief crack in the –Y vertical strut forward facing TPS was still present, but not nearly as pronounced as had been observed with LCC firing room OTV. A small area of frost was observed on the +Y longeron TPS closeout with LCC firing room OTV during de-tanking. No TPS anomaly was observed in this area during the post drain inspection.

The only ice remaining was located in the LO2 feedline bellows, -Y aft fairing-to-ET/SRB cable tray interface, the lower EB fittings, and on the ET/ORB umbilical purge vents.

In summary, no IPR conditions and no flight hardware concerns were detected during the post drain inspection. There are no constraints for the next cryoload.

4.0 LAUNCH

4.1 PRE-LAUNCH SSV/PAD INSPECTION

The Post-Drain and additional T-8 hour inspection of the Pad and SSV performed as a result of the weather scrub satisfied the pre-launch inspection requirement. No new issues or concerns were detected.

4.2 FINAL INSPECTION

The Final Inspection of the cryoloaded vehicle was performed from 1130 to 1300 hrs on 10 August 2001 during the two-hour built-in-hold at T-3 hours in the countdown. There were no Launch Commit Criteria (LCC) or OMRS criteria violations. There was no acreage icing concerns. There was also no protuberance icing conditions outside of the established database.

A portable Shuttle Thermal Imager (STI) infrared scanning radiometer was utilized to obtain vehicle surface temperature measurements for an overall thermal assessment of the vehicle, particularly those areas not visible from remote fixed scanners, and to scan for unusual temperature gradients.

4.2.1 ORBITER

No Orbiter tile or RCC panel anomalies were observed. The RCS thruster paper covers were intact with none discolored. Ice/frost had formed all the way around the SSME #2 heat shield-to-nozzle interface and from the 6 to 9 o'clock position around the SSME #1 heat shield-to-nozzle interface.

4.2.2 SOLID ROCKET BOOSTERS

No SRB case, closeout, or protuberance anomalies were observed. SRB case temperatures measured by the STI radiometers were close to ambient temperatures, ranging from 80 to 88 degrees F. All measured temperatures were above the minimum requirement.

4.2.3 EXTERNAL TANK

The ice/frost prediction computer program 'SURFICE' was run as a comparison to infrared scanner point measurements. The program predicted temperatures above the 32 degrees F throughout ET cryoload. The following table shows ambient condition, SURFICE prediction and IR surface temperatures at the start of FIT walkdown. As was the case during the first launch attempt, the difference between the predicted SURFICE temperatures and the IR surface readings can be attributed to the fact that there was a significant amount of sunlight striking the surface of the external tank during the inspection. The SURFICE Ice Prediction Program does not take into account the effect the sun has on the ET surface temperatures.

Ambient conditions – 1100hrs	SURFICE Predictions	IR Surface Readings
82 Degrees F.	LO2 ogive 67 Degrees F	LO2 Tank 72-90 Degrees F
78% RH	LO2 barrel 64 Degrees F	
5 knots	LH2 upper 65 Degrees F	LH2 Tank 76-92 Degrees F
030 degrees	LH2 lower 70 Degrees F	

The Final Inspection Team observed very light condensation on the LO2 tank acreage. No acreage ice/frost formations were observed. There were no TPS anomalies.

No significant anomalies were present in the intertank TPS. No cracks were observed in the intertank stringer valley TPS. Small frost spots were detected over fastener heads in the 4th and 5th valleys –Z of the –Y thrust panel (approximately 10 to 12 inches below the LO2 to intertank flange closeout. This is acceptable per NSTS 08303 and is not unusual for a second tanking operation. Ice and frost accumulations on the GUCP were typical.

The LH2 tank was wet with moderate condensate on the upper portion and significantly more condensation at the aft end. There were no acreage TPS anomalies.

Typical amounts of ice/frost had accumulated in the LO2 feedline bellows and support brackets.

A 4 inch long and 3/8 inch wide stress relief crack was observed in the –Y vertical strut TPS with no offset. This condition has been observed on previous vehicles and found acceptable for flight per the NSTS-08303 criteria.

A small frost spot was detected on the inboard aft face of the –Y Vertical Strut. This frost spot was dissipating as time went on due to all the condensate running off in the area. There were no TPS anomalies on the LO2 ET/ORB umbilical. Ice and frost in the LH2 recirculation line bellows and on both burst disks was typical. Likewise, a typical amount of ice/frost had accumulated on the LH2 ET/ORB umbilical purge barrier outboard side, forward, and aft surfaces. Typical ice/frost fingers were present on the pyro canister and plate gap purge vents. No unusual vapors or cryogenic drips had appeared during tanking, stable replenish, and launch.

4.2.4 FACILITY

All SRB sound suppression water troughs were filled and properly configured for launch. No leaks were observed on the GUCP or the LO2 and LH2 Orbiter T-0 umbilicals.

4.3 T-3 HOURS TO LAUNCH

After completion of the Final Inspection on the pad, surveillance continued from the Launch Control Center. Twenty-two remote-controlled television cameras and two infrared radiometers were utilized to perform scans of the vehicle. No anomalies were detected during this timeframe.

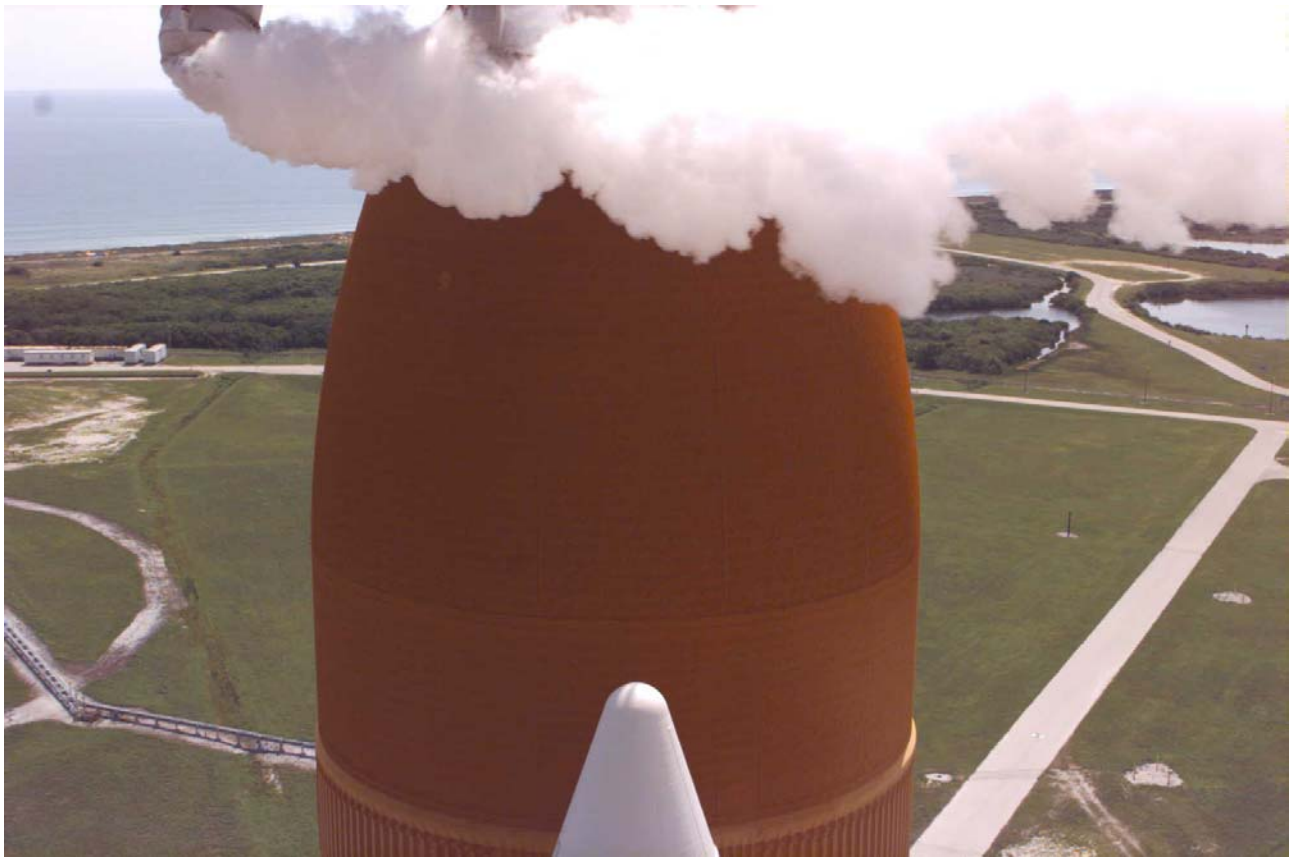


Photo 3: LO2 tank acreage.

Very little condensate was present on the LO2 tank acreage. Surface temperature ranged from 72 to 90 degrees Fahrenheit. There were no acreage TPS anomalies.

Photo 4: Overall view of Launch Vehicle and view of LH2 tank.

The LH2 tank was wet with moderate condensate on the upper portion and significantly more condensation at the aft end. Surface temperature ranged 76 to 92 degrees Fahrenheit. There were no acreage TPS anomalies.

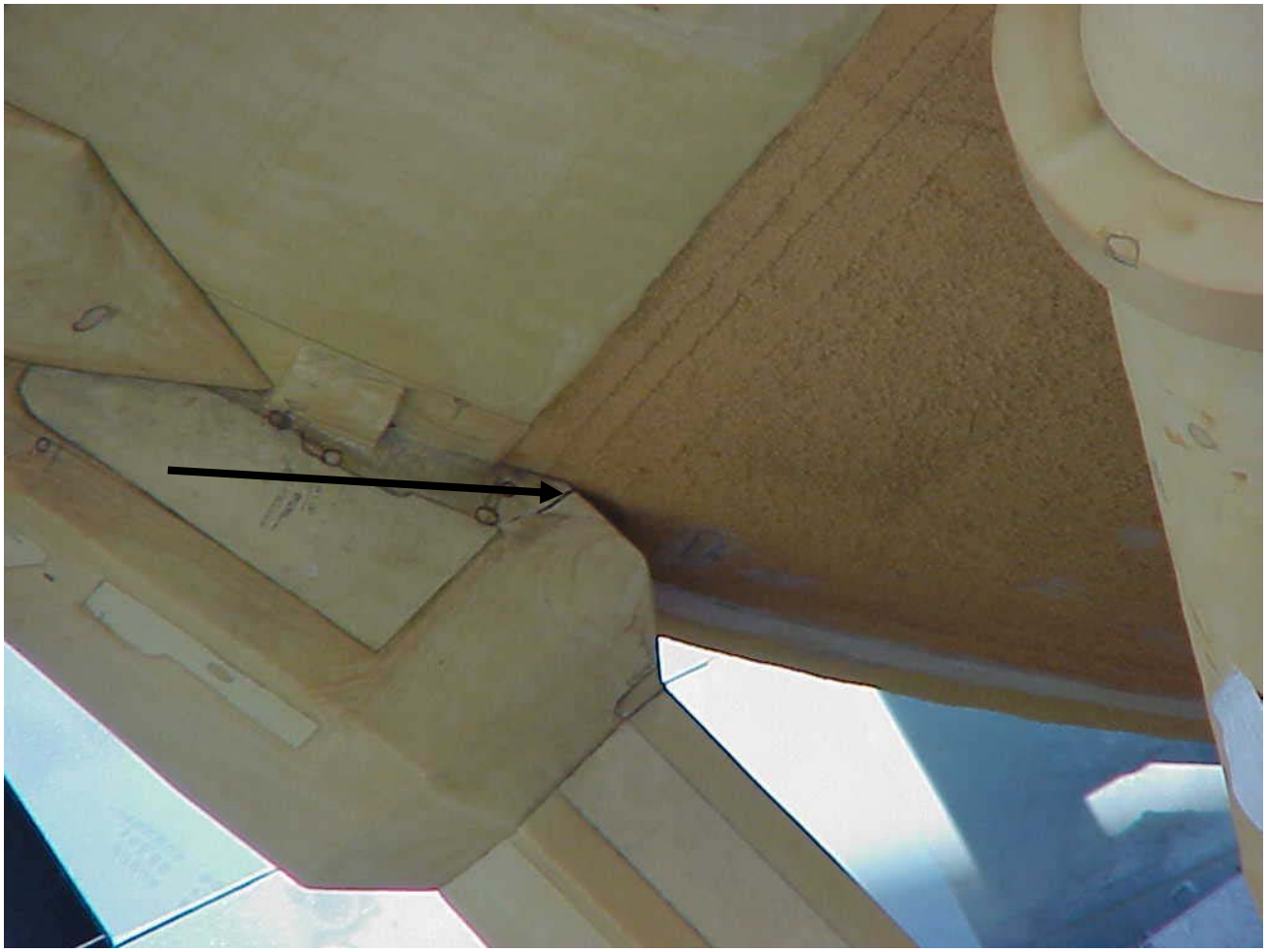


Photo 5: Crack in –Y Vertical Strut TPS

A 4 inch long and 3/8 inch wide stress relief crack was observed in the –Y vertical strut TPS with no offset. This condition has been observed on previous vehicles and found acceptable for flight per the NSTS-08303 criteria.

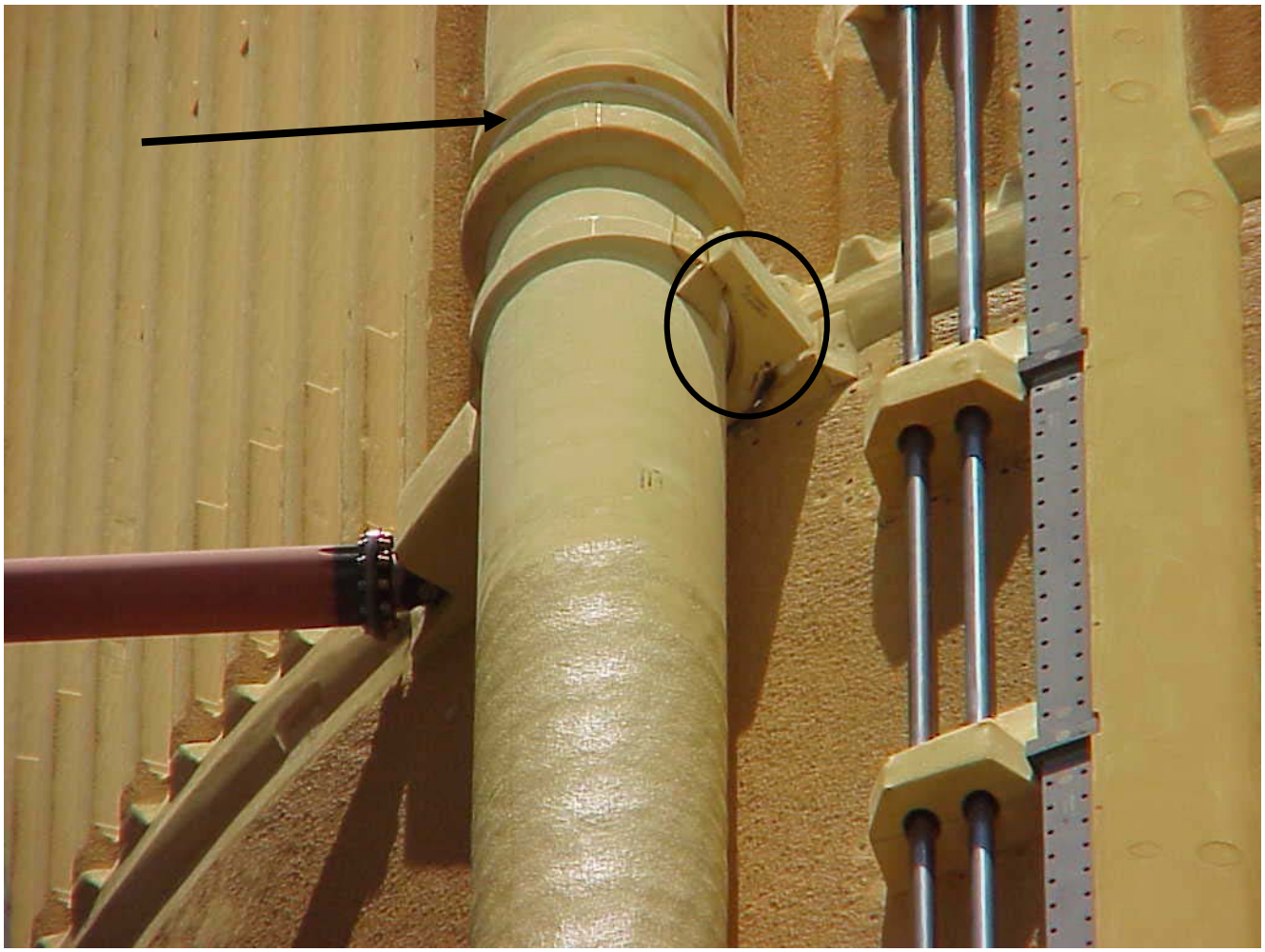


Photo 6: Ice/Frost on LO2 F/L

Typical ice/frost on the LO2 feedline support bracket attachments and in forward bellows.

5.0 POST LAUNCH PAD DERBIS INSPECTION

The post launch inspection of the MLP-3, Pad A FSS and RSS was conducted on 10 August 2001 from Launch + 2 to 3.5 hours (1900 to 2030 EST). No flight hardware was found.

Orbiter liftoff lateral acceleration data to predict stud hang-ups received from Boeing-Huntington Beach indicated that no SRB holddown stud hang-up had occurred, the reported value was 0.138g. Evaluation of the MLP 0-level was performed and the south holddown studs were visually assessed as having no indication of hang-up. Erosion was typical for the north posts with some evidence of missing RTV at the HDP haunch interface. North holddown post blast covers and T-0 umbilical exhibited minimal exhaust plume damage. Both SRB aft skirt GN2 purge lines were intact, protective tape layering was partially eroded, the metal braid was visible only on the LH purge line.

The LO2 and LH2 Tail Service Masts (TSM) appeared undamaged and the LO2 bonnet was observed to have closed properly. The MLP deck was in generally good shape. A section of handrail on west side of the MLP deck was bent and had loose bolts. OTV-054 camera located on the east side of the MLP received extensive launch damage but no missing hardware was noticed. All MLP deck communication connector caps were found intact and secured.

The GH2 vent line latched in the eighth of eight teeth of the latching mechanism. The GUCP 7-inch QD sealing surface exhibited no damage. The deceleration cable was in nominal configuration, and the vent line blanket was sooted and in generally good condition.

The OAA appeared to be intact with no evidence of plume impingement.

All slidewire baskets were secured with no evidence of damage.

The GOX vent arm, hood, ducts and structure appeared to be in good shape with no indications of plume damage.

Debris findings included:

- A piece of twisted sheet metal 10 feet long by 18 inches wide was found near the box car area.
- An A/C duct clamp was found on deck grating at FSS 175 foot levels.

Overall, damage to the pad appeared to be minimal. Minimal debris was noted on pad apron and FSS.

Photo 7: General view of MLP post launch.

Typical erosion on North holddown posts and blast shields.

6.0 FILM REVIEW

No significant anomalies were observed during the review of the STS-105 films and videos that would had been required to be elevated to the Mission Management Team, Shuttle managers, vehicle systems engineers, and to Program Integration.

6.1 LAUNCH FILM AND VIDEO SUMMARY

A total of 68 films and videos, which included 16mm films, 35mm films, and Operational Television Video (OTV) camera videos, were reviewed starting on launch day.

Film Item E-18 shows cylindrical shaped debris coming into view at GMT 21:10:15.643 (approx. T+1.5 seconds). As the item falls and tumbles it maintains a cylindrical shape. The debris is possibly a 2 ½ to 3 inch long by 0.75-inch diameter facility bolt. After review of film item E-12, the bolt appears to originate from the SRB Holddown post #5 haunch area. The debris was not observed to contact flight hardware.

Debris particle fell along the upper surface of LH wing, near the inboard/outboard elevon split. First seen at GMT 09:04:00.715 near the outboard edge of inboard elevon. There was no observed contact with flight hardware noted. (E-77)

SRB separation appeared normal. (E-207, E-212,)

SSME Mach diamond formation sequence was 3-2-1 (E-76, -77)

Small amount of free-burning GH2 blown in a south-westerly direction by wind. (E-76, E-52)

Particles of SRB aft-skirt instafoam fell along side the SRB plume. (E-207, E-212)

Body flap and elevon movement during ascent were typical. (E-220, E-212)

A piece SRB water trough baggie observed moving upward and then aspirated by plume near RH SRB aft skirt between HDP #2 and #4.

Facility debris observed passing through field of view outboard of LH wing tip near FSS. (E-36) Ice particles fell from ET/ORB umbilicals after lift-off. No impact to orbiter lower surface was noted. (E-31, E-36, E-52, E-63)

Tile surface coating material was lost from aft face of RH OMS RCS stinger. This is a common occurrence due to SSME ignition acoustics. (E-19)

Charring on the ET aft dome was less than typical. (E-207)

Umbilical purge barrier baggie material fell during roll maneuver. (E-52, E-207)

Forward RCS paper covers were observed falling aft during early ascent.

Localized flow condensation observed at various points on the vehicle.

Numerous pieces of facility debris entered field of view well after vehicle cleared tower. (E-36, E-40).

No stud hang up, or ordnance fragments, were observed on any of the SRB hold-down posts.

Deluge water pipe leaking adjacent to HDP 3, water dripping on MLP deck. (E7, E-10)

Debris (probable SRB throat plug material RTV) ejected from adjacent to HDP 4, no vehicle contact noted. (E-7, E-15)

Throat plug material ejected from SRB exhaust hole after T-0. No contact with vehicle. (E-52)

The lens ports on the protective boxes on cameras E-7 and E-10 were shattered approximately 4 to 5 seconds after T-0. The lens port stayed with the camera box and did not become dislodged.

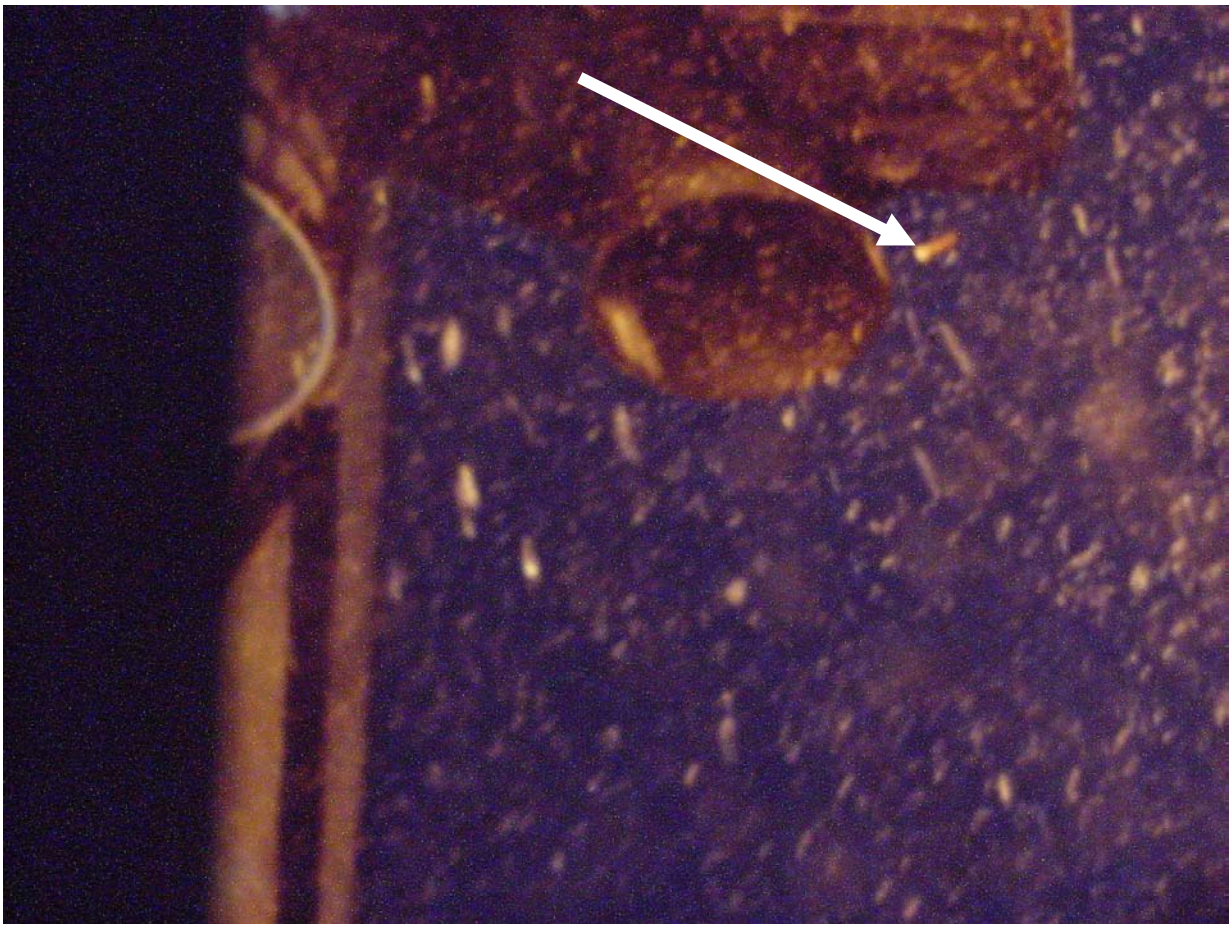


Photo 8: Cylindrical debris seen on E-18

Probably 2 ½ to 3 inch long by 0.75-inch diameter facility bolt from HDP #5 haunch.

6.2 ON-ORBIT FILM AND VIDEO SUMMARY

16mm film motion picture film from the LH2 umbilical cameras, as well as the 35mm still images from the LO2 ET/ORB umbilical camera and Crew Hand-Held Still Images, of the External Tank after separation from the Orbiter were received and reviewed at KSC on 29 August 2001.

ET separation from the Orbiter was normal. There was no protrusion of the EO-2 and EO-3 separation bolt visible

No damage was detected on the LO2 ET/ORB umbilical disconnect, sealing surfaces, or closeout TPS. Typical ablation and divoting was noted on the vertical portion of the umbilical cable tray.

There was an 8-inch diameter divot, with foam still partially attached, observed on the +Y thrust strut near the forward flange.

Divot observed on the LH2 tank near the base of the LO2 feedline support bracket closeout at station Xt-1377. Missing foam (2-inches by 6-inches) observed on the LH2 tank acreage near the Xt-1270 location. Remainder of LH2 tank acreage appeared nominal.

Small divots observed on the intertank-to-LH2 tank flange between the bipods.

Evaluation of the thrust panel TPS was difficult due to lighting condition and image resolution.

No anomalies were detected in the LO2 tank acreage. The BSM burn scars appeared typical.

The ablation/erosion of LO2 feedline flange closeouts appeared typical. Two small divots observed on the feedline at approximately station Xt-1270.

35mm umbilical film had no coverage LO2 ogive section. Evaluation of this area was difficult with 16mm film and handheld imagery due to image resolution.

6.3 LANDING FILM AND VIDEO SUMMARY

A total of 15 films and videos, which included eight 35mm large format films and nine videos, were reviewed.

The landing gear extended properly. Drag chute deployment appeared normal. No anomalies were detected from touchdown through rollout. No unusual tile damage was visible in the films.

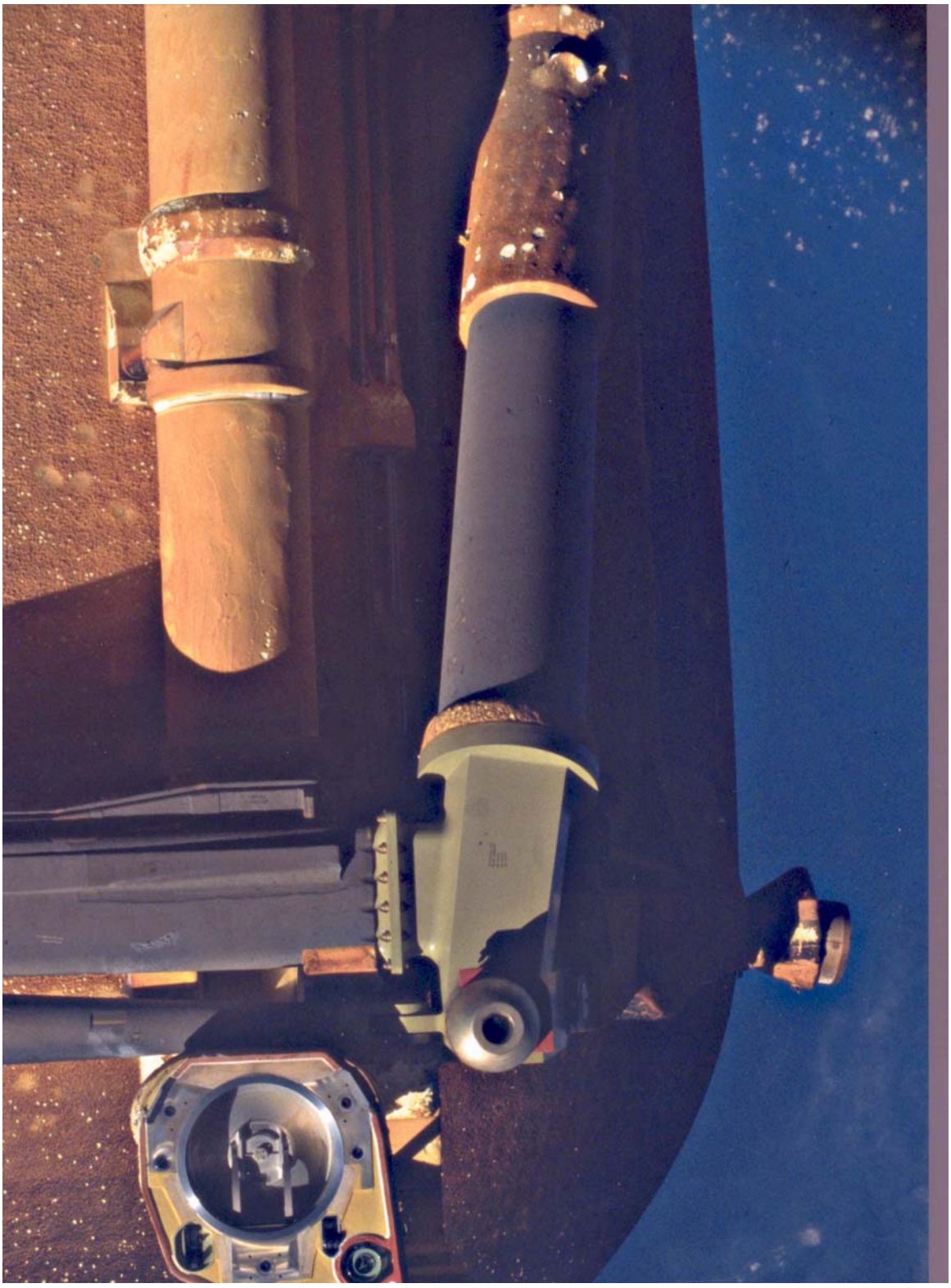


Photo 9: ET LO2 ET/ORB Umbilical

An 8-inch diameter divot, with foam still partially attached, was located on the +Y thrust strut near the forward flange. Several smaller divots (less than 2 inch dia.) on +Y thrust strut. Erosion of the LO2 feedline flange closeouts appeared typical.

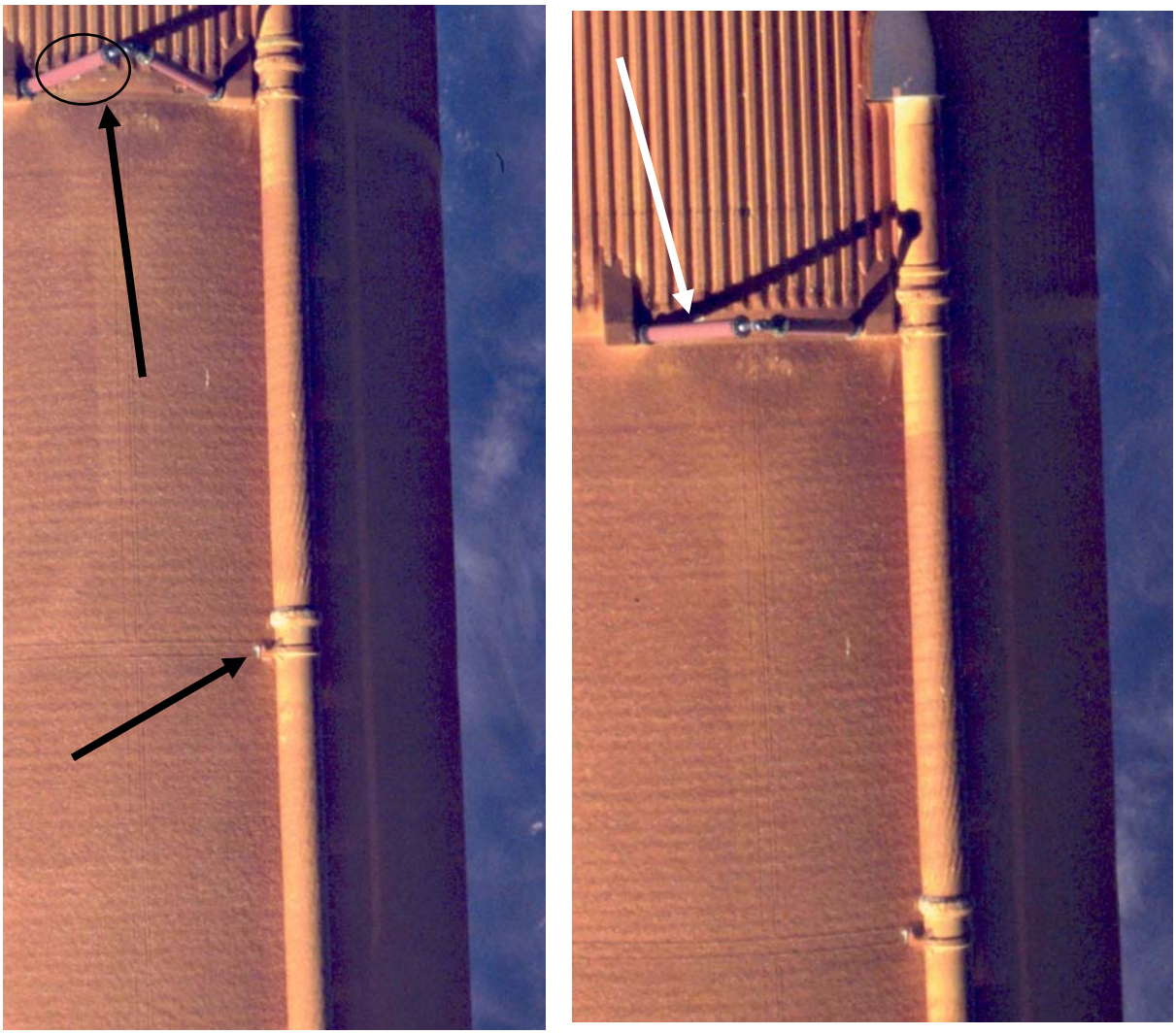


Photo 10: Divots in LH2 Tank Flange Closeout and in LH2 Tank Acreage

Small divots observed on the intertank-to-LH2 tank flange between the bipods. Divot observed on the LH2 tank near the base of the LO2 feedline support bracket closeout at station Xt-1377.

7.0 SRB POST FLIGHT/RETRIEVAL DEBRIS ASSESSMENT

The BI-109 Solid Rocket Boosters were inspected for debris damage and debris sources at CCAFS Hangar AF on 13 August 2001. Generally, both boosters appeared in excellent condition.

The RH SRB top/left position forward BSM cover was missing. Preliminary examination of the fracture plane revealed no sooting effects, this is indicative of water impact damage.

The TPS on both frustums exhibited no debonds/unbonds. There was minor localized blistering of the Hypalon paint visible.

All seven remaining BSM aero heat shield covers appeared fully opened and locked, but one RH and two LH cover attach rings had been bent at the hinge by parachute riser entanglement

The forward skirts exhibited no debonds or missing TPS. RSS antennae covers/phenolic base plates were intact, though one layer of the LH SRB +Z antenna phenolic base plate had delamination at the –Y edge.

The Field Joint Protection System (FJPS) and the System Tunnel Covers closeouts were visibly in good condition with no unbonds observed.

Separation of the aft ET/SRB struts appeared normal.

Aft skirt external surface TPS appeared in good condition. Typical blistering of Hypalon paint was visible on the BTA insulation close-outs and GEI cork runs.

The holddown post Debris Containment Systems (DCS) appeared to have functioned normally except on HDP No. 2 which was fully obstructed by the frangible nut halves. This condition most likely happened at water impact.

No indication of stud hang up was observed.

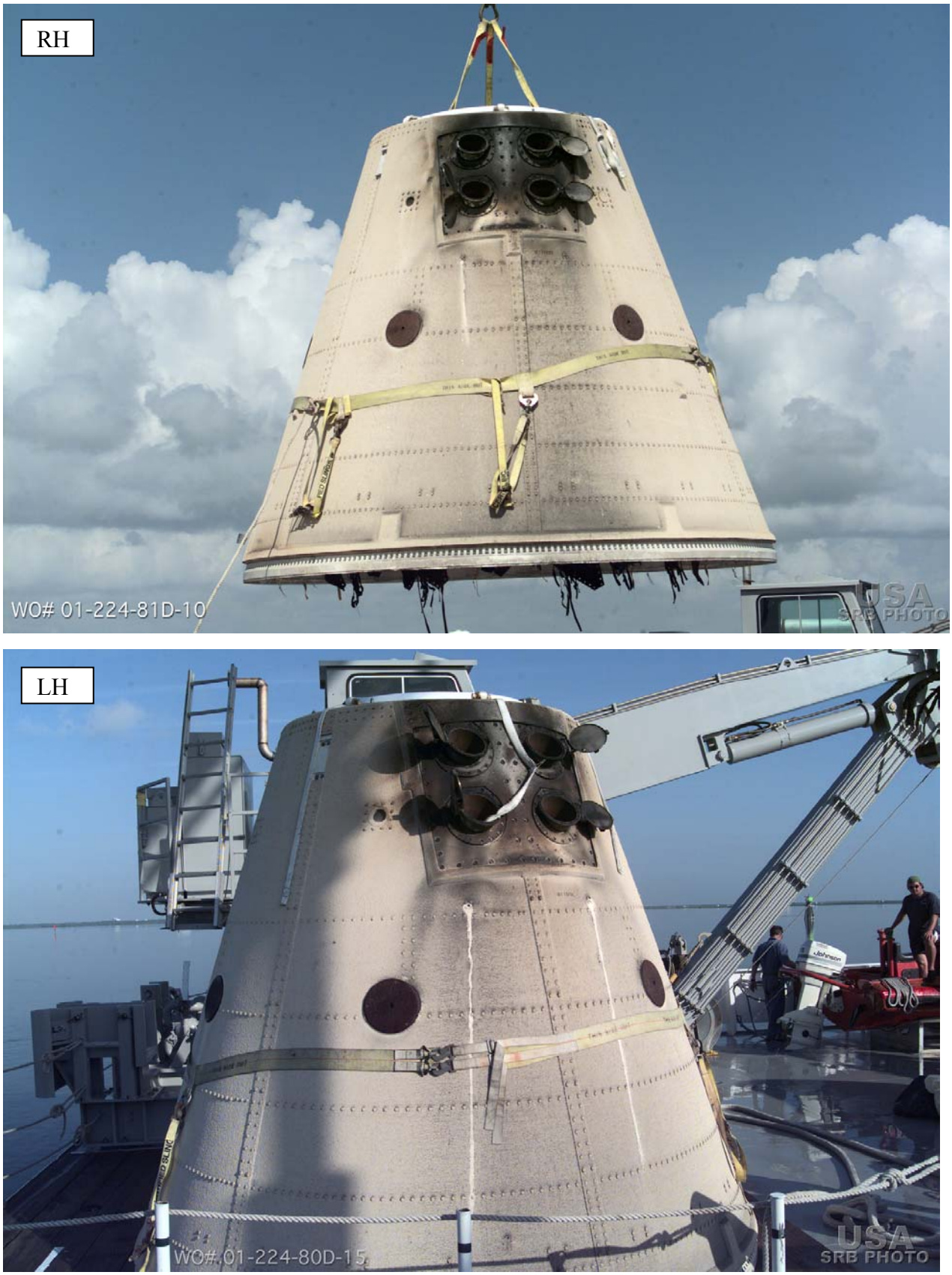


Photo 11: Frustum Post Flight Condition

The frustums exhibited no debonds/unbonds or missing TPS.
Seven of eight BSM aero heat shield covers had locked in the typical opened position. One cover from RH frustum was missing.

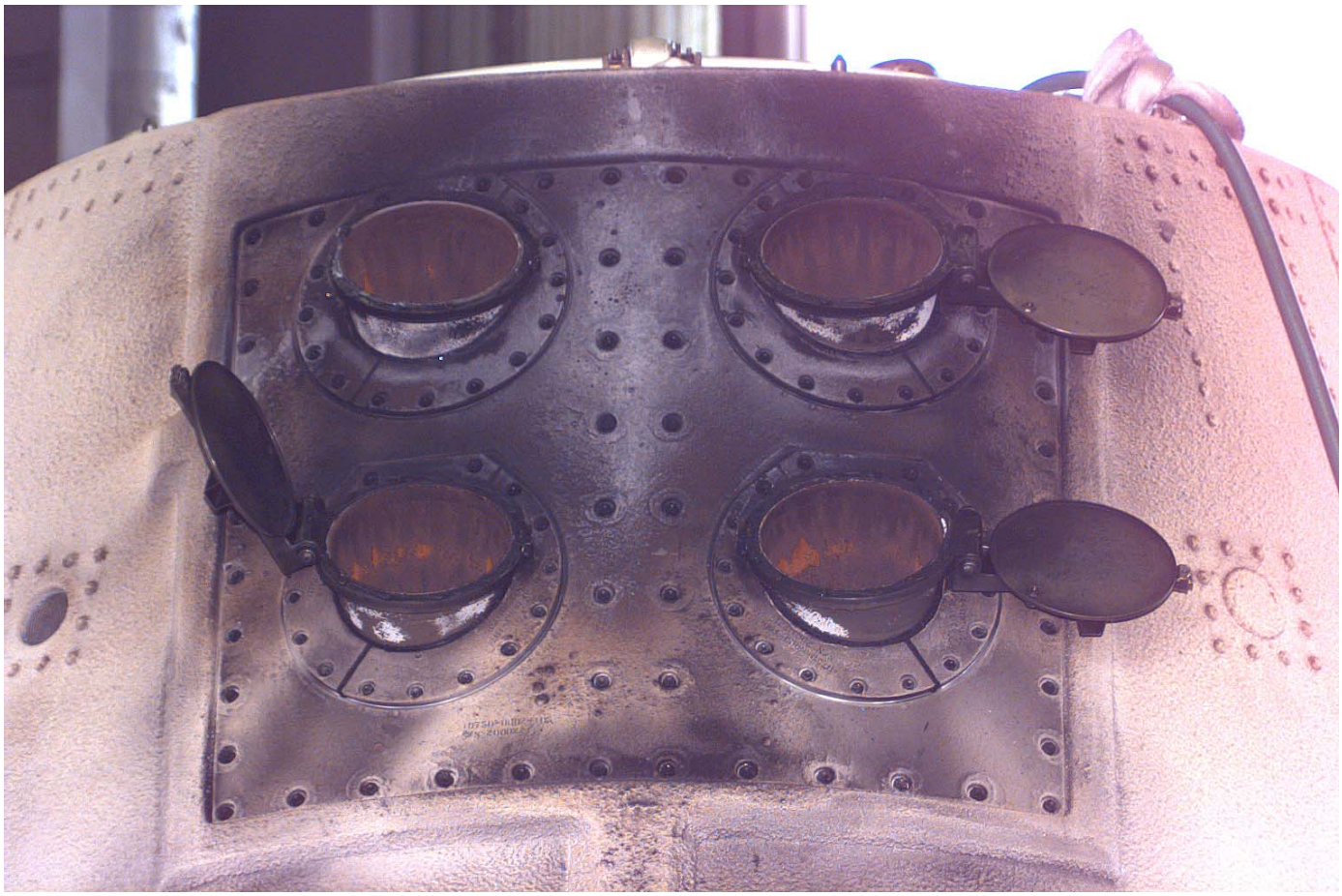


Photo 12: RH Frustum Post Flight Condition

The RH SRB top/left position forward BSM cover was missing. Fracture plane revealed no sooting effects, this is indicative of water impact damage.

Photo 13: SRB Post Flight Condition

Both SRB's were found in good condition regarding debris assessment

8.0 ORBITER POST LANDING DEBRIS ASSESSMENT

After the 2:23 p.m. local/eastern time landing on 22 August 2001, a post landing inspection of OV-103 Discovery was conducted at the Kennedy Space Center on SLF runway 15 and in Orbiter Processing Facility bay 2. This inspection was performed to identify debris impact damage and, if possible, debris sources.

The Orbiter TPS sustained a total of 144 hits of which 25 had a major dimension of 1-inch or larger. This total does not include the numerous hits on the base heat shields attributed to SSME vibration/acoustics and exhaust plume recirculation.

The following table lists the STS-105 Orbiter damage hits by area:

	HITS > 1-inch	TOTAL HITS
Lower Surface	15	108
Upper Surface	2	3
Window Area	8	32
Right Side	0	0
Left Side	0	0
Right OMS Pod	0	1
Left OMS Pod	0	0
TOTALS	25	144

The Orbiter lower surface sustained 108 total hits, of which 15 had a major dimension of 1-inch or larger, both numbers are well within family. The majority of the hits (57 total with 11 greater than 1-inch) were located in the area from the nose landing gear to the main landing gear wheel wells on both left and right chines. The pattern and size ratio of these hits is indicative of damage from ET foam loss. This is the highest number of hits in this area since the implementation of ET intertank foam venting. Analysis of ET separation film will further aid in the determination of debris sources.

Approximately 31 of the total lower surface hits were around the LH2 umbilical area. Most of these damage sites around the ET/ORB umbilical were most likely caused by pieces of the umbilical purge barrier flailing in the airstream and contacting tiles before pulling loose and falling aft.

The largest lower surface tile damage site, located on the LH chine area, measured 5-inches long by 4-inches wide by 0.0625-inches deep. The cause of this damage has not been determined yet.

The landing gear tires were reported to be in good condition.

ET/Orbiter separation devices EO-1, EO-2, and EO-3 functioned normally. No ordnance fragments were found on the runway beneath the umbilicals. The EO-2 and EO-3 fitting retainer springs appeared to be in nominal configuration, though one of the “salad bowl” clips was missing from EO-3. This condition was present prior to Orbiter/ET mate and was accepted per MR approval for unrestricted use back in 1999 via PR STR-5-14-3015. The EO-2/3 pyro debris shutters were fully closed. No debris was found beneath the umbilicals.

Typical amount of tile damage occurred on the base heat shield. All SSME Dome Heat Shield closeout blankets were in good condition.

Three vertical tail leading edge tile damage sites were observed, with two having a major dimension greater than one inch. There was one tile damage site on the leading edge of the RH OMS Pod.

There were a total of 32 hits, with 8 having one dimension greater than 1-inch, on the window perimeter tiles. Hazing and streaking of forward-facing Orbiter windows appears to be normal

The post-landing walkdown of Runway 15 was performed immediately after landing. All components of the drag chute were recovered and appeared to have functioned normally. Several FOD items were found on the runway. The debris items found were: a 13-inch long, 10-gauge, metallic wire; a 1-inch long by 0.625-inches wide by 0.250 inches thick metal fragment, and numerous pieces of SLF concrete. All of which were found within 10 feet of the center-line. Additionally, there were numerous pieces of asphalt found on the approach threshold of runway 15.

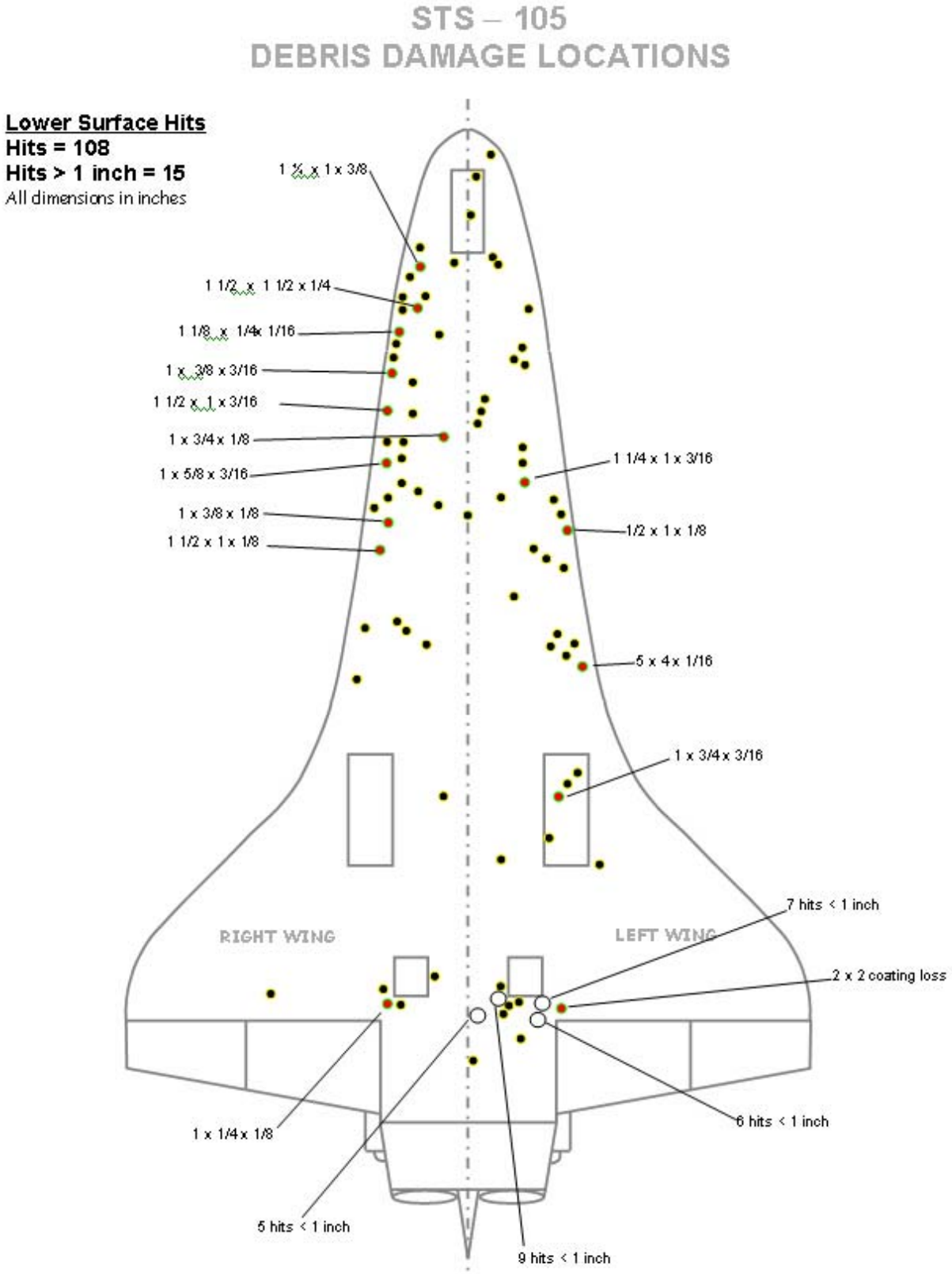


Figure 1: Orbiter Lower Surface Debris Damage Map

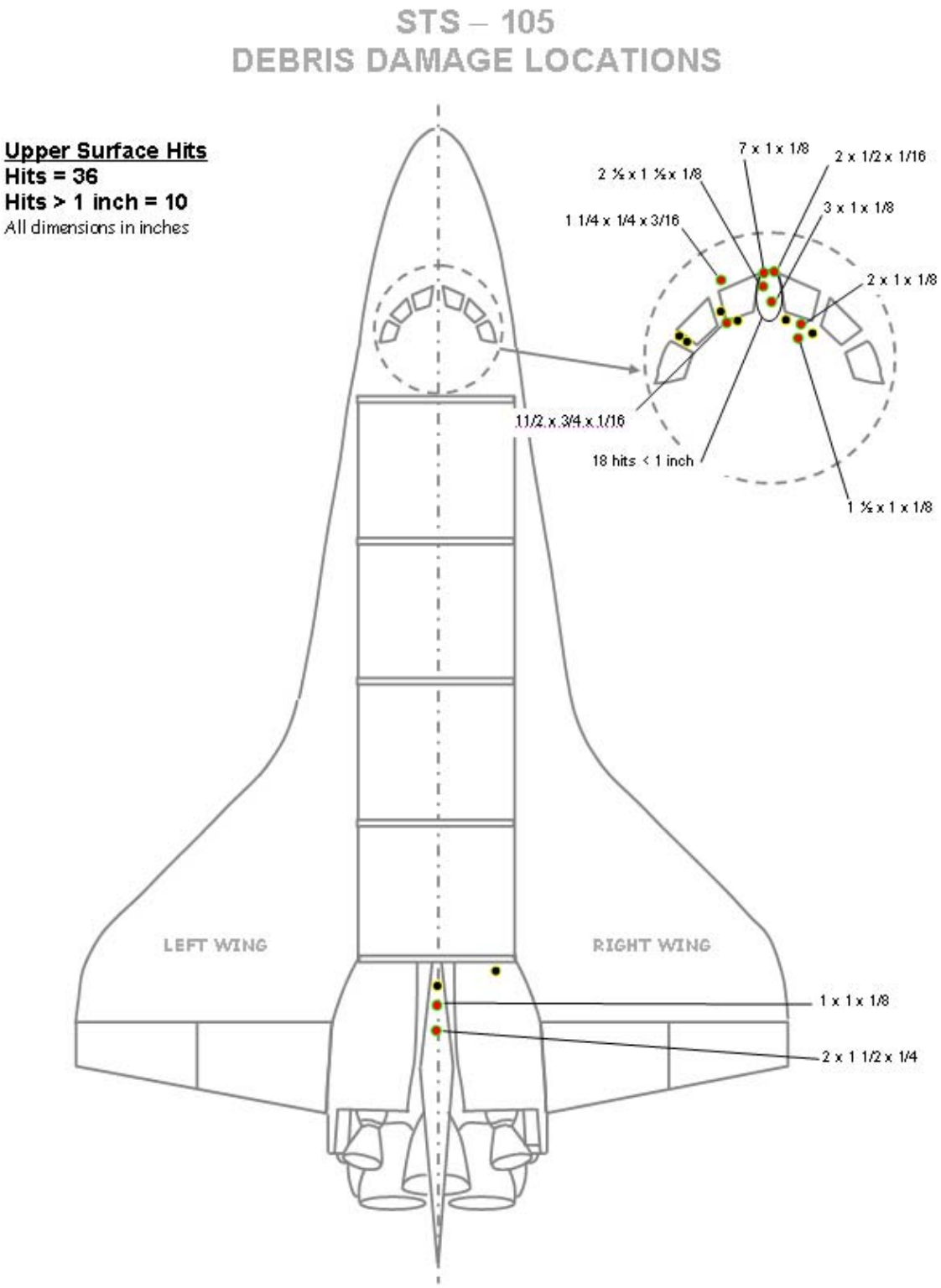


Figure 2: Orbiter Upper Surface Debris Damage Map

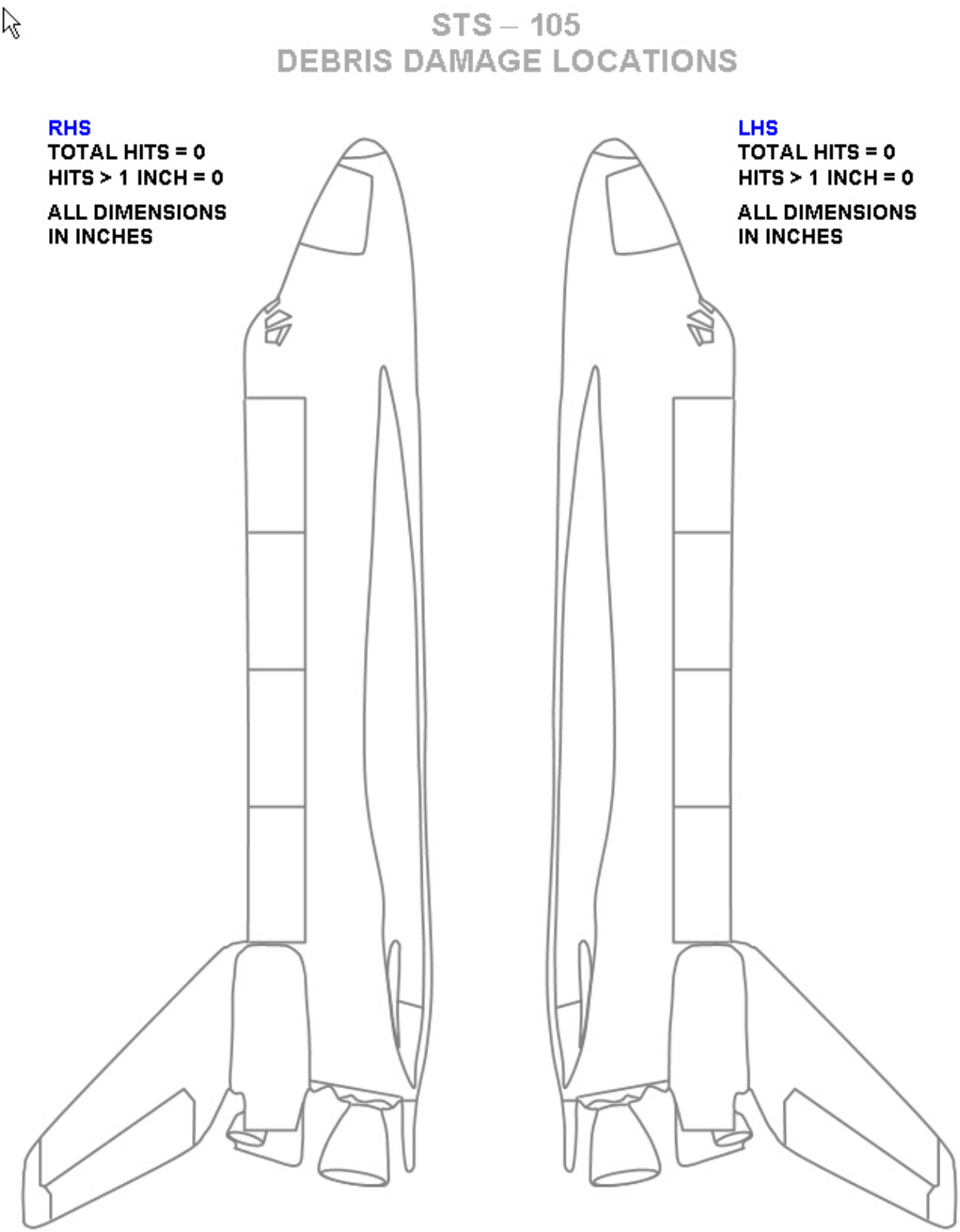


Figure 3: Overall View of Orbiter Sides

STS NUMBER	LOWER SURFACE		ENTIRE SURFACE	
	HITS > 1 INCH	TOTAL HITS	HITS > 1 INCH	TOTAL HITS
STS-70	5	81	9	127
STS-69	22	175	27	198
STS-73	17	102	26	147
STS-74	17	78	21	116
STS-72	3	23	6	55
STS-75	11	55	17	96
STS-76	5	32	15	69
STS-77	15	48	17	81
STS-78	5	35	12	85
STS-79	8	65	11	103
STS-80	4	34	8	93
STS-81	14	48	15	100
STS-82	14	53	18	103
STS-83	7	38	13	81
STS-84	10	67	13	103
STS-94	11	34	12	90
STS-85	6	37	13	102
STS-99	21	75	25	88
STS-101	19	70	27	113
STS-106	17	73	17	105
STS-92	14	86	24	127
STS-97	10	78	10	84
STS-98	8	73	13	102
STS-102	10	44	15	100
STS-100	4	42	13	92
STS-104	24	108	26	126
AVERAGE	11.6	63.6	16.3	103.3
SIGMA	6.1	32.0	6.2	27.4
STS-105	15	108	25	144

MISSIONS STS-86,87,89,90,91,95,88,96,93,103 ARE NOT INCLUDED SINCE THESE MISSIONS HAD SIGNIFICANT DAMAGE CAUSED BY KNOWN DEBRIS SOURCES

Figure 4: Orbiter Post Flight Debris Damage Summary

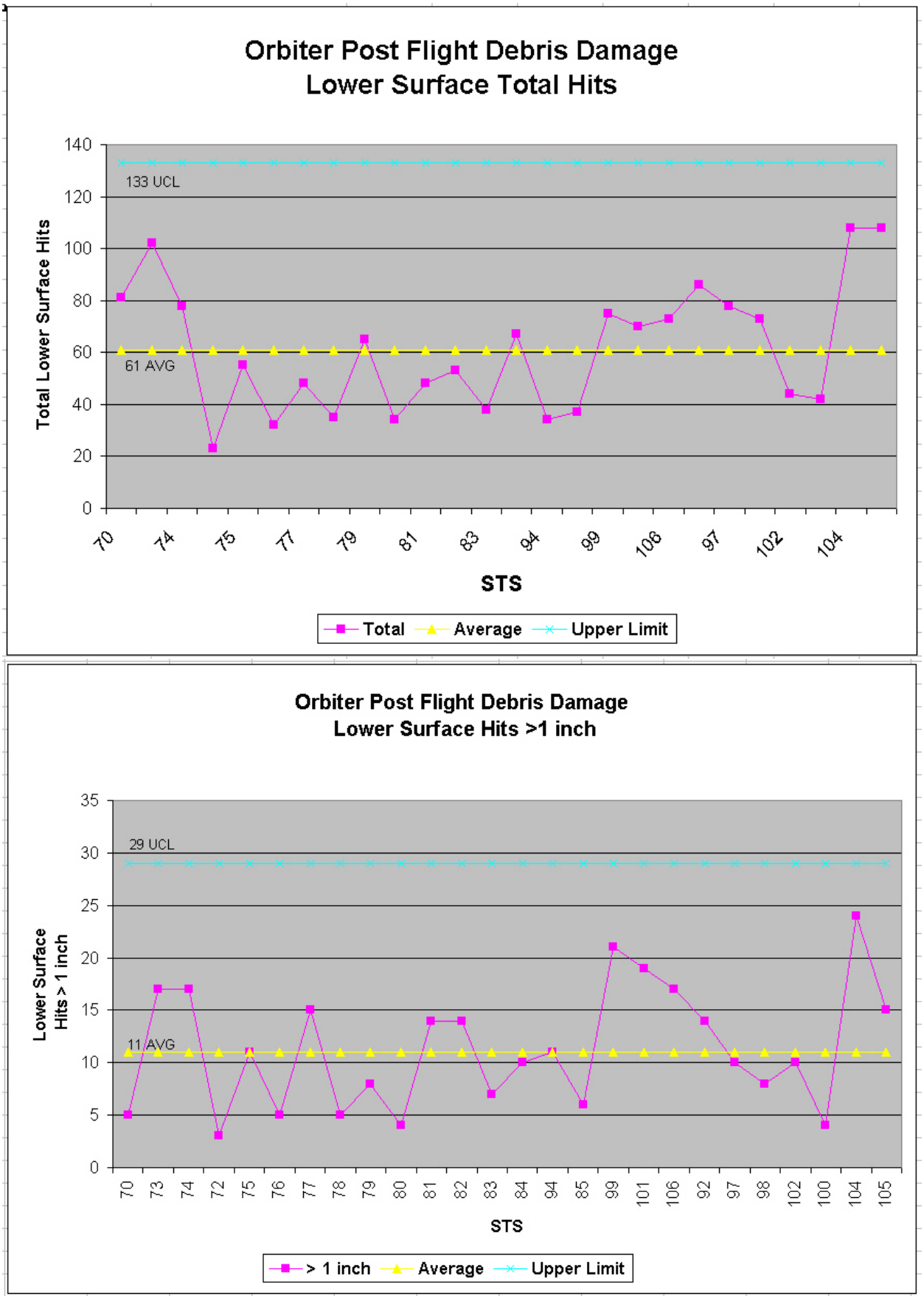
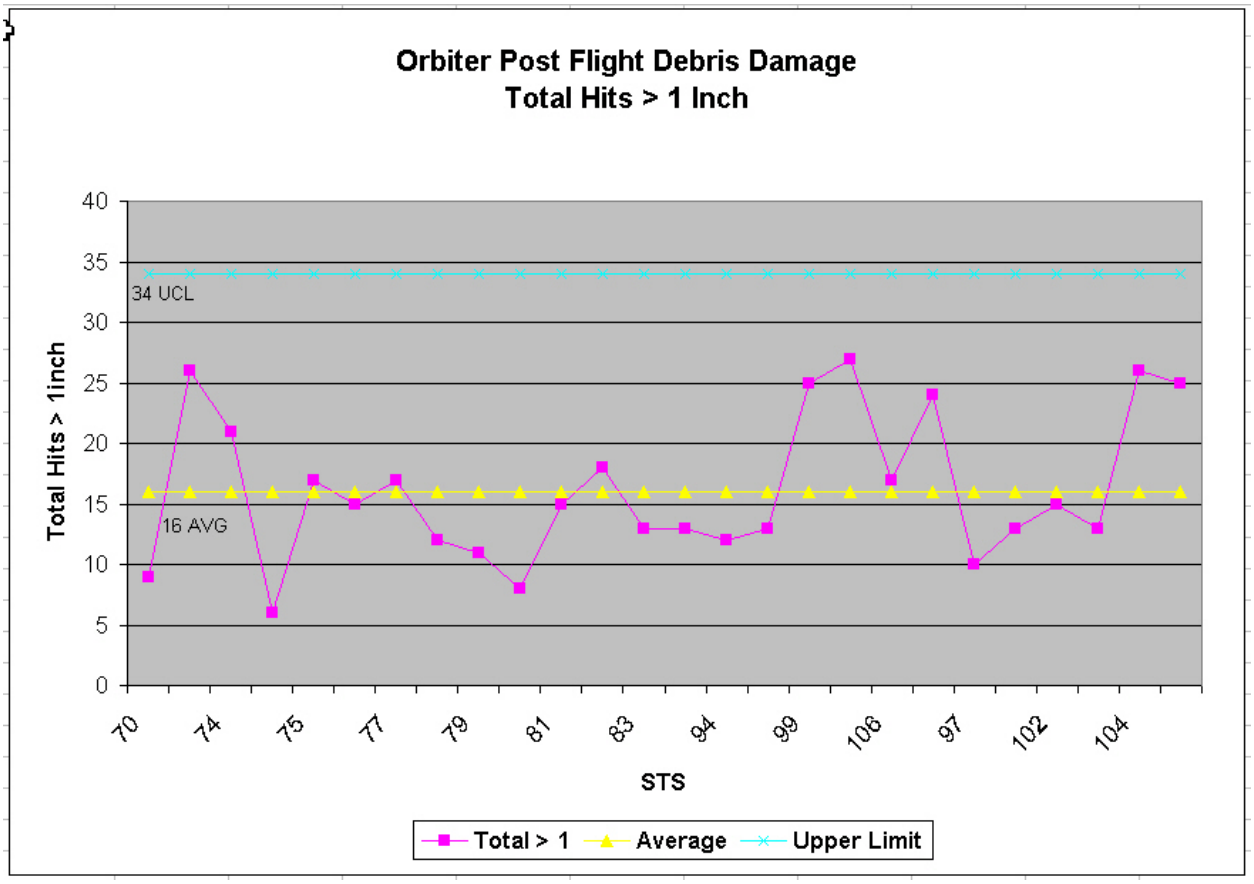


Figure 5: Control Limits for Lower Surface Hits



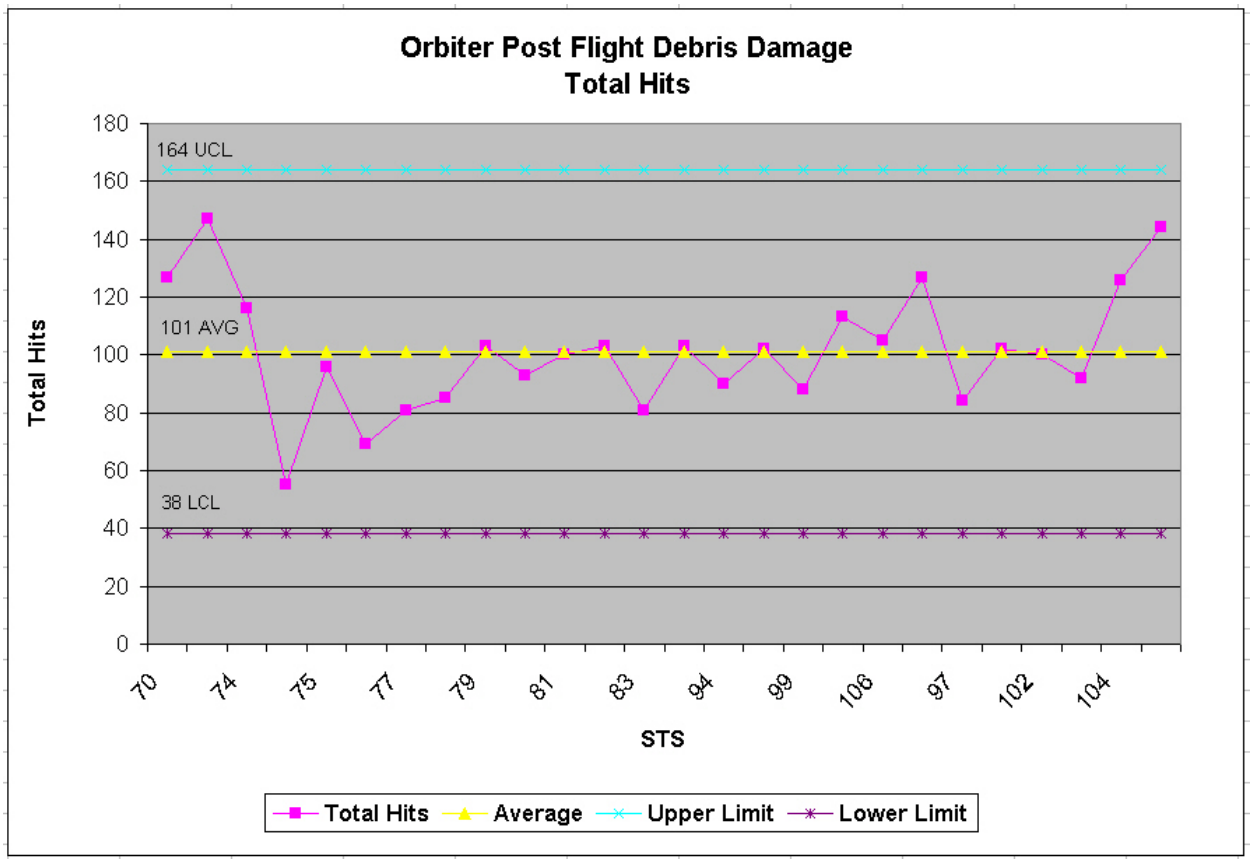


Figure 6: Control Limits for Total Hits

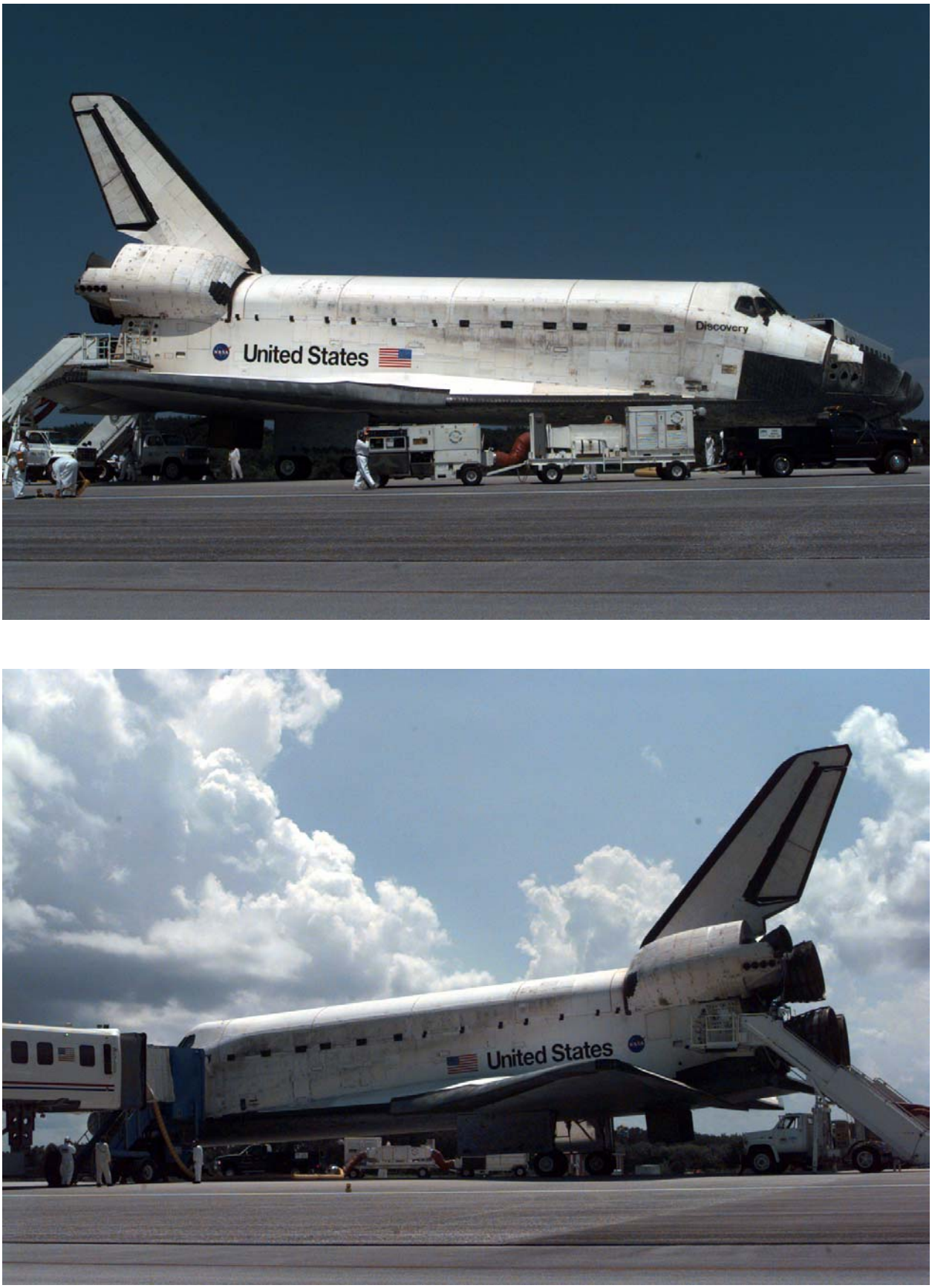


Photo 14: Overall View of Orbiter sides

The orbiter lower surface sustained 108 total hits, with 15 having a dimension greater than 1-inch. Both the total number of Orbiter TPS debris hits and the number of hits 1-inch or larger were within established family.

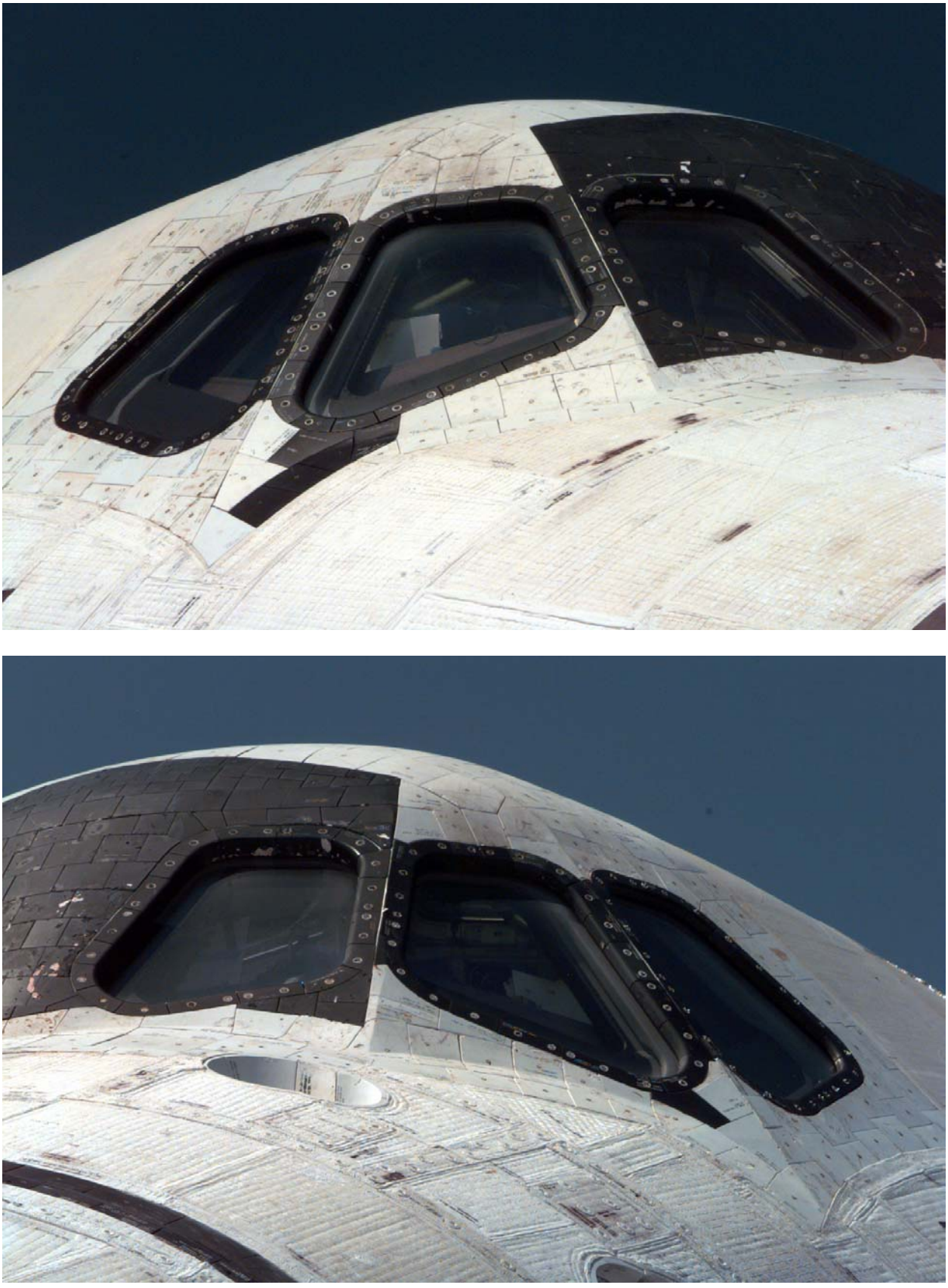


Photo 15: Overall View of Orbiter Windows

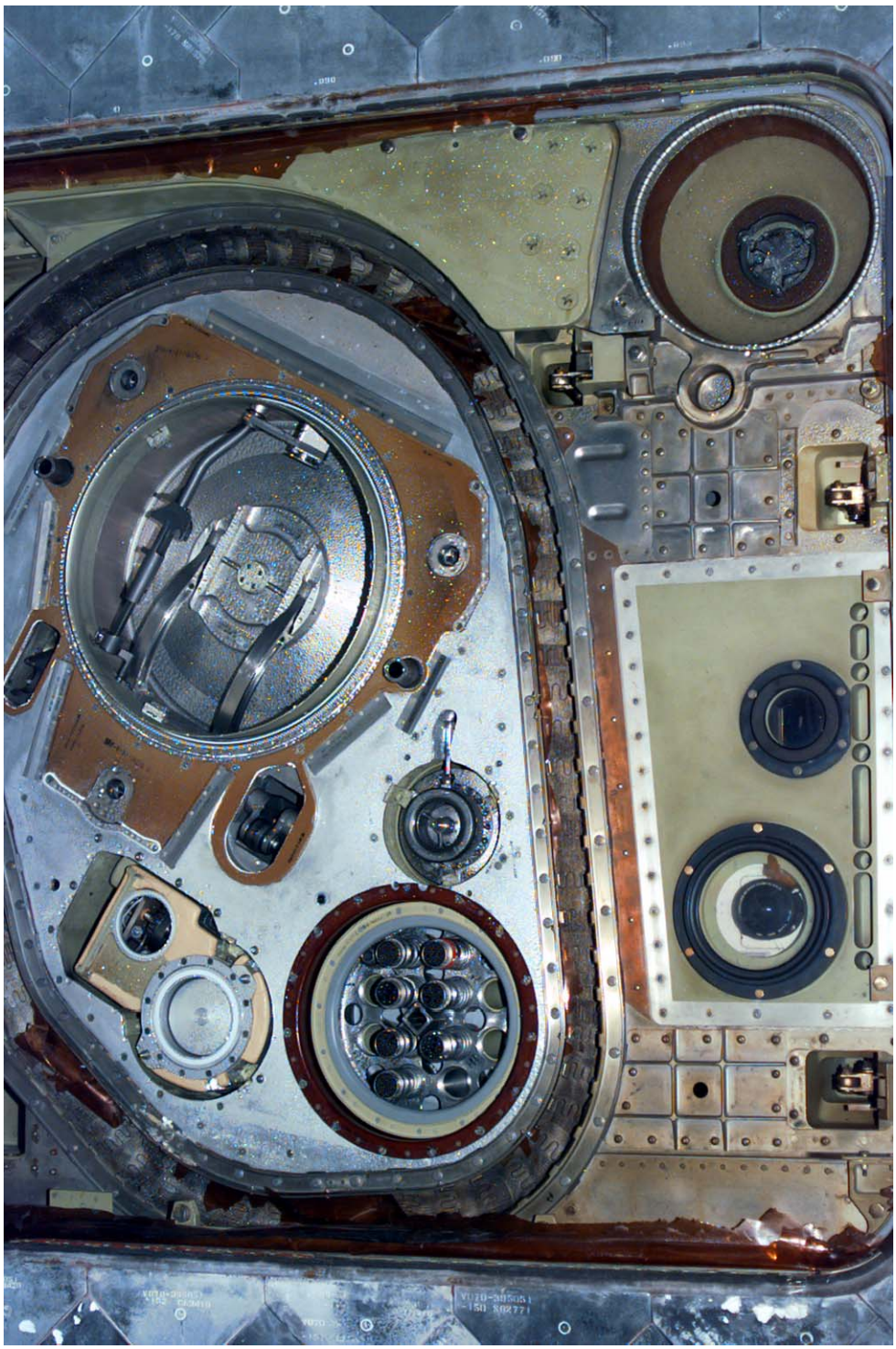


Photo 16: ORB/ET LH2 Umbilical

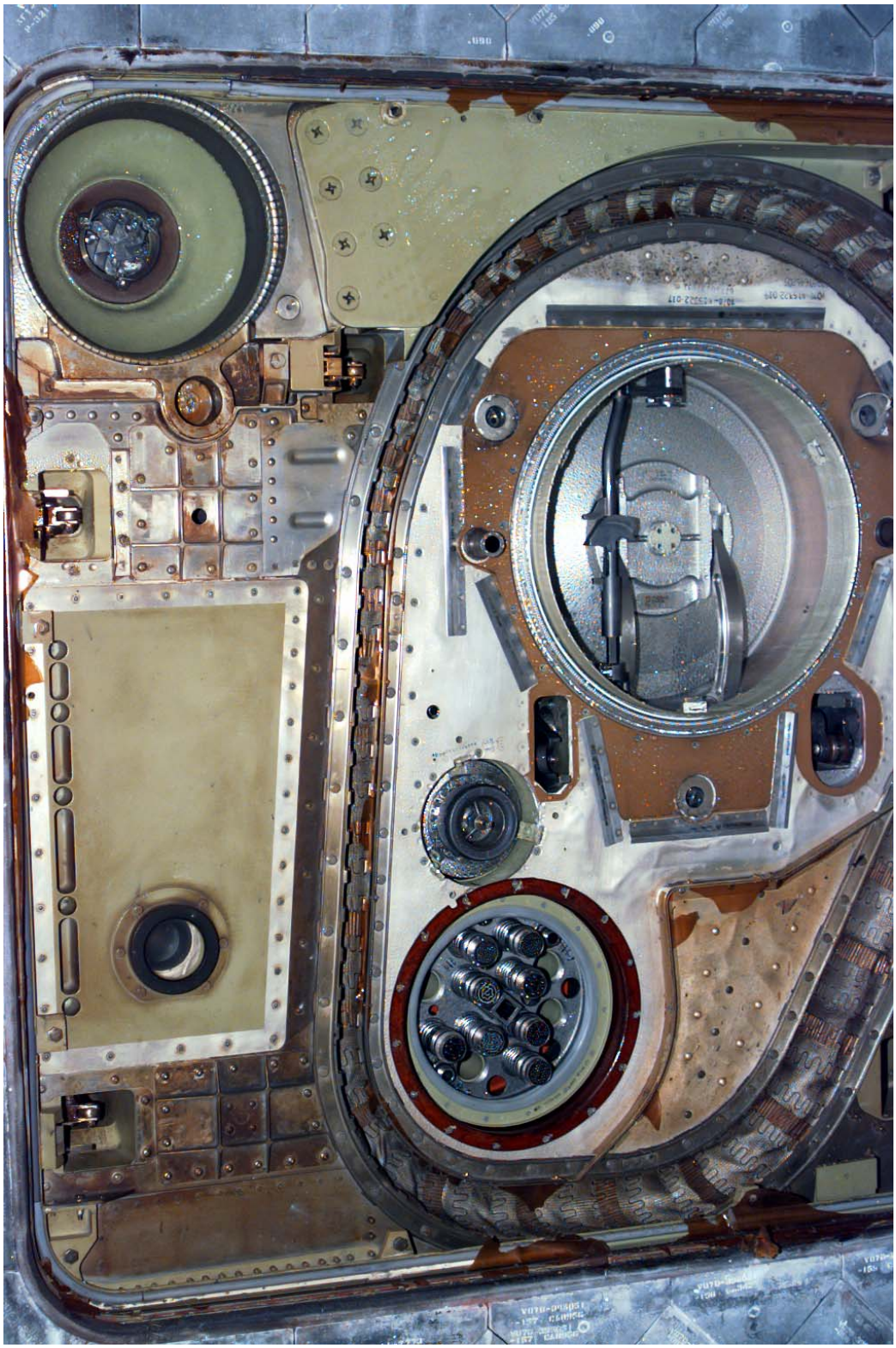


Photo 17: ORB/ET LO2 Umbilical

9.0 DEBRIS SAMPLE LAB REPORTS

Window wipe samples from Orbiter windows 1 thru 8 were submitted to the KSC Microchemical Analysis Branch (MAB) for material/chemical identification analysis and comparison to known STS materials. The results of this analysis are summarized below.

Sample residuals provided indication of Orbiter Thermal Protection System (TPS) materials, metallics and metallic corrosion, paint, natural landing site, and organic materials.

Post-landing sample results provided no new information or trend data for debris source analysis.

10.0 POST-LAUNCH ANOMALIES

Based on the debris walkdowns and film/video review, the only post-launch anomalies was the cylindrical debris (probably a facility bolt) observed in film item E-18. Shuttle Ground Operations performed an evaluation of all pre-launch walkdowns and inspections. It was determined that the debris went undetected due to being lodged in a crevice of the mobile launch platform (MLP) SRB haunch area. In order to prevent this from occurring in the future, more detailed inspections are to be performed in all areas of the MLP. Inspections will include borescope inspections in all locations not readily visible.

APPENDIX A. JSC PHOTOGRAPHIC ANALYSIS SUMMARY

Table of Contents

Tables and Figures

1. STS-105 (OV-103): Film/Video Screening and Timing Summary

1.1 Screening Activities

1.1.1 Launch

The STS-105 launch of Discovery (OV-103) from Pad 39A occurred on August 10, 2001 at 222:21:10:14.029 UTC as seen on camera E12. SRB separation occurred at approximately 21:12:15.869 UTC as seen on camera KTV13.

On launch day, 22 videos were received and screened. Video from camera OTV048 was not received. (ET208 is no longer provided). No timing data was received on the second engineering replays (cameras ET204, ET207, ET212, ET213). The focus is soft on the long range tracking views (probably caused by atmospheric haze).

Twenty launch films were screened and a report was sent to the Shuttle Program distribution on August 13, 2001. Twenty-one additional films were received for contingency support and anomaly resolution. (Camera E33 had an incorrect field-of-view. Camera film E208 has been discontinued.)

One anomalous event was seen during the review of the STS-105 launch films and videos that was elevated to the Launch + 4 Day KSC, JSC, MSFC Film/Video Analysis Teams Consolidated Film Review Report. See Section 2.1. No anomalous events were seen during the review of the STS-105 landing films or on the on-board films of the External Tank that were elevated to the Landing + 3 Day KSC, JSC, MSFC Film/Video Analysis Teams Consolidated Film Review Report (These reports consolidate the multi-center post flight photo reviews into a single list of observations for engineering review. This integrates the photo review process into the IFA / PRACA process to ensure that the identified observations are assessed and dispositioned prior to the next flight per established problem reporting criteria).

One 16mm umbilical well camera flew on STS-105. The 35mm umbilical well TPS camera film and the crew handheld still photography and video of the External Tank were acquired. See Section 2.3.

1.1.2 On-Orbit

No unplanned on-orbit Shuttle support tasks were requested.

Pre-planned, real-time analysis support was provided to the ISS AF-7A.1 Space Station photographic and television external survey. The Space Station image analysis support will be documented in the AF-7A.1 Imagery Overview Report.

1.1.3 Landing

Discovery made a daylight landing on runway 15 at the KSC Shuttle Landing Facility on August, 22, 2001 (234:18:22:39.304 UTC). Eleven videos and ten landing films were received.

The landing touch down appeared normal. The drag chute deploy sequence appeared normal on the landing imagery. Using available video including NASA-Select, no anomalous events were seen during the Orbiter approach, landing, and landing rollout.

Post landing, a sink rate analysis of the STS-105 main landing gear was performed for the main gear touchdown. See Section 2.5.

According to the pre-mission agreement, the STS-105 landing films were not screened due to budgetary constraints.

2. Summary of Significant Events

2.1 KSC, JSC, MSFC Film / Video Analysis Teams Consolidated Film Review Reports

One anomalous event was seen during the review of the STS-105 launch films that was elevated to the Launch +4 day Intercenter Consolidated Film Review Report.

Figure 2.1 Cylindrical-Shaped Debris During Liftoff (Camera E18)

An unidentified, thin, cylindrical-shaped, rigid-appearing, piece of debris was seen falling from near the LH2 TSM T-0 umbilical disconnect and past the left RCS stinger 1.5 seconds after

liftoff (21:10:15.725 UTC) on the MLP camera film E18. See Figure 2.1. This debris appeared light-colored on one end and a red-brown color on the other end. (The size of the object could not be determined because the distance of the object from the camera was not known.) On camera film E12, a very small piece of debris was detected near the Holddown Post M-5 haunch area. The debris was seen to loop upward in the direction of camera E18, moving right to left in the view. The debris was first seen at 21:10:14.218 UTC, which is approximately the same time that the cylindrical-shaped debris was seen on camera film E18. It was concluded that the debris seen on camera E12 was probably the same piece of debris that was seen on camera E18. KSC personnel stated that the object was probably a bolt from a handrail or access ladder to the SRB haunch area. A post-launch investigation was intiated at KSC to identify possible debris sources and establish future prevention methods.

No anomalous events were seen on the STS-105 landing films or on the films of the External tank that were elevated to the Landing +3 day Intercenter Consolidated Film Review Report.

2.2 Other Launch Observations

2.2.1 Debris from SSME Ignition through Liftoff

Figure 2.2.1 (A) Ice Contacts LH2 Cable Tray (Camera OTV054)

Multiple pieces of ice debris were seen falling from the ET/Orbiter umbilicals and along the –Z side of the body flap during SSME ignition through liftoff. Two pieces of umbilical ice debris were seen to contact the LH2 umbilical well door sill during SSME ignition (21:10:09.825 UTC and 21:10:14.596 UTC). A single piece of umbilical ice debris from the forward (+X) surface of the ET / Orbiter LO2 umbilical fell aft and contacted the +X surface of the LO2 electric cable tray (21:10:10.793 UTC). See Figure 2.2.1 (A). No damage to the launch vehicle was detected. Umbilical ice debris contacting the Orbiter surfaces has been seen on previous missions. (Ice from the forward (+X) side of the LH2 ET / Orbiter umbilical well was seen falling past the LH2 four inch recirculation line, but no contact with the launch vehicle was noted.) (Cameras OTV009, OTV054, OTV061, OTV063, E4, E5, E17, E18, E19, E20, E31, E63)

A small, light-colored piece of debris was seen falling aft near the LSRB aft ET / Orbiter attach brace (21:10:09.635 UTC). (Camera E31)

A piece of unidentified dark-colored debris was seen traveling in a +Y direction from the FSS and along the –Z side of the left outboard elevon before falling aft (21:10:11.7 UTC). (Camera E31)

A single piece of debris (probably a piece of RCS paper or frost / ice) was seen coming from the –Z side of the right RCS stinger (near the +Y corner) prior to liftoff (21:10:12.161 UTC). (Camera OTV051)

A light-colored piece of unidentified debris was seen falling aft from the top of the view between the Orbiter and the ET in an area between the –Y ET thrust strut and the –Y longeron during liftoff (21:10:15.191 UTC). (Camera E31)

A piece of debris (possibly water baffle material) was seen north of the launch pad during liftoff (21:10:15.744 UTC). (Camera E52)

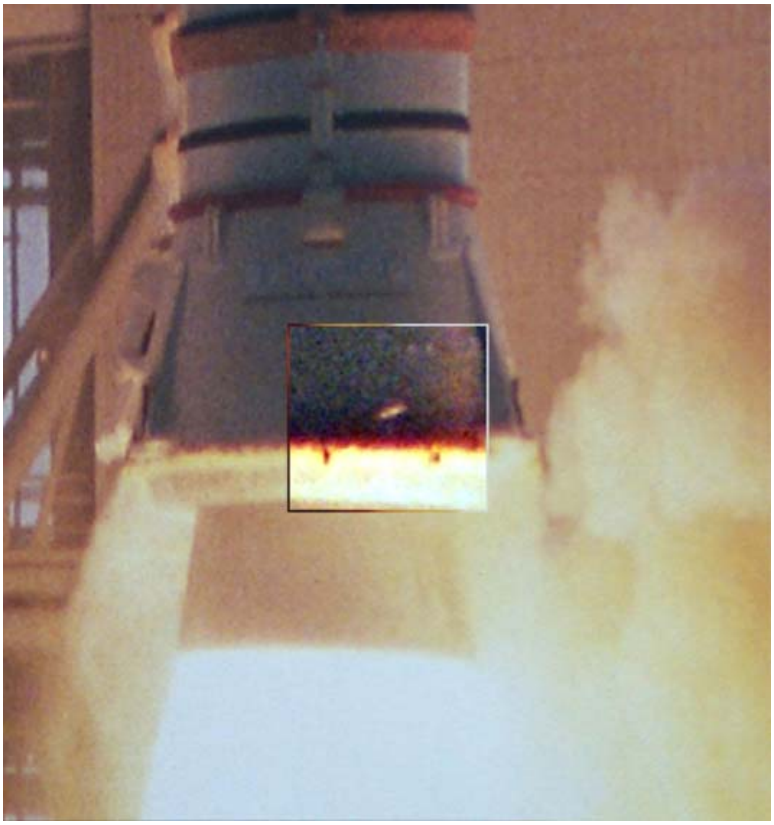


Figure 2.2.1 (B) Debris Near RSRB Aft Skirt During Liftoff (Camera E52)

A small piece of debris was seen near the RSRB aft skirt during liftoff on camera E52 (21:10:15.600 UTC). On the camera E4 film, a piece of debris was seen arcing upward from the RSRB aft skirt area toward the ET aft dome at liftoff. Also on camera E4, a second piece of debris was seen arcing upward from the LSRB aft skirt area toward the ET aft dome at liftoff. None of these debris were seen to contact the launch vehicle. (Cameras E1, E4, E52)

Two pieces of dark-colored debris were seen after SRB ignition and during liftoff on the camera E7 view of RSRB holddown post M-4. One of the pieces of the debris was first seen coming from between the water pipes and the RSRB aft skirt (21:10:15.071 UTC).

A thin, dark, flat piece of material (possibly a piece of EPON shim material or a very small piece of water baffle material) was seen at the RSRB holddown post M-1 between the RSRB foot and the holddown post shoe. This piece of material appeared to move in an upward direction with the shoe during liftoff. (Camera E8)

A single, long piece of flexible debris was seen near the RSRB holddown post M-4 at liftoff (21:10:15.100 UTC). (Camera E15)

2.2.2 Debris During Ascent

Multiple pieces of debris, too numerous to count (mostly umbilical ice and RCS paper debris), were seen falling aft of the launch vehicle during ascent. See Table 2.2.2 (A).

Event Time	Event Description
21:10:27.639 UTC	ET / Orbiter umbilical ice falling between the body flap and the LSRB (Camera E224)
21:10:28.300 UTC	Probable ET/Orbiter umbilical ice debris (Camera E54)
21:10:29.731 UTC	ET / Orbiter umbilical ice falling along the body flap (Camera E52)
21:10:31.013 UTC	RCS debris from right RCS stinger (Camera E54)
21:10:31.071 UTC 21:10:32.215 UTC 21:10:34.000 UTC	RCS paper debris falling aft in SSME #1 exhaust plume (Camera E224)
21:10:30.986 UTC 21:10:34.339 UTC	Debris (probable forward RCS paper) was seen near the right OMS pod and falling aft along the +Z surface of the right wing (Camera E52)
21:10:31.076 UTC	RCS paper debris seen in SSME exhaust plume (Camera E223)
21:10:39.997 UTC 21:10:41.092 UTC	ET / Orbiter umbilical ice debris seen falling along the body flap (Camera E223)
21:10:44.671 UTC	Probable RCS paper debris from the left RCS stinger seen near SSME #1 (Camera E223)

Table 2.2.2 (A) RCS Paper and Umbilical Ice Debris During Ascent

A single piece of debris (probably umbilical purge barrier material) was seen falling aft into the SSME exhaust plume during ascent (21:10:34.137 UTC). (Camera E223)

An unidentified, light-colored piece of debris was seen forward of the RSRB aft skirt before falling aft along the RSRB exhaust plume during ascent (21:10:29.731 UTC). On camera E224, a small light-colored piece of debris was first seen forward of the LSRB aft skirt and then fell aft along the SRB exhaust plume (21:10:43.261 UTC). (Cameras E52, E224)

Figure 2.2.2(A) Debris Spray Seen Exiting the SRB Exhaust Plume (Camera E223)

As on previous missions, debris was seen exiting the SRB exhaust plumes. The debris exiting the SRB exhaust plumes during the majority of the ascent was probably instafoam from the aft end of the SRB's. The more dense appearing debris near the time of tail-off, just prior to SRB separation, was probably SRB slag debris. Examples of this debris can be seen in Table 2.2.2 (B).

Event Time	Event Description
21:10:38.872 UTC	Camera E54
21:10:46.101, 21:10:49.011, and 21:11:09.053 UTC	Camera E223
21:11:04.028 UTC	Camera E224
21:11:22.152 UTC	Camera KTV4A
21:11:22.274 UTC	A large single piece of debris was seen breaking into three or four pieces before falling aft along the SRB exhaust plume (Camera E223)
21:11:22.477 UTC	Several pieces of debris seen falling aft along the SRB exhaust plume (Camera E223)
21:12:11.732 UTC	Camera KTV13
21:12:13.400 UTC	Camera KTV13
21:12:13.589 UTC	A small very faint appearing piece of debris was seen falling aft along the SRB exhaust plume. (Camera E223)
Camera E207-frames 7287 and 7394	Frames 7287, 7394: Several pieces of debris were seen near the LSRB exhaust plume. (Camera E207)

Table 2.2.2 (B) Debris Seen Exiting the SRB Exhaust Plume

A single light-colored piece of debris was seen between the aft portion of the RSRB and the aft portion of the –Z side of the ET during ascent (~21:11:03 UTC). The source and identity of this debris was not determined. (Camera ET207)

2.2.3 Mobile Launch Platform (MLP) Events

The SSME ignition appeared normal. During SSME start-up, the SSME Mach diamonds formed in the expected sequence (3, 2, 1). The new Block IIA engines did not fly on STS-105. (Cameras E19, E20, E76). The times for the Mach diamond formation given in Table 2.2.3 are from film E20:

SSME	TIME (UTC)
SSME #3	21:10:10.743
SSME #2	21:10:10.902
SSME #1	21:10:11.083

Table 2.2.3 SSME Mach Diamond Formation Times

Orange vapor (possibly free burning hydrogen) was seen near the base of the vertical stabilizer, near the base heat shield, and on the –Z side of the body flap during SSME ignition. Orange vapor forward of the aft end of the Orbiter during SSME ignition has been seen on previous mission films and videos. (Cameras OTV070, E2, E5, E18, E19, E20, E76, E63)

Frost was seen on the –Y ET nose cone vent louver during liftoff. Frost on the ET vent louvers has been seen on previous mission imagery. (Camera OTV061)

Light-orange-colored streaks were seen in the SSME exhaust plumes, possibly debris induced, after SSME ignition and prior to liftoff at the times shown below (Cameras E19, E20, E76):

SSME #1 - 21:10:11.296, 21:10:11.304 UTC
SSME #2 - 21:10:10.917, 21:10:10.937, 21:10:11.035, 21:10:11.083 UTC
SSME #3 - 21:10:11.208, 21:10:12.077, 21:10:12.080, 21:10:12.161, 21:10:12.221 UTC

Streaks in the SSME exhaust plume prior to liftoff have been seen on previous mission films.

Typical of previous missions, small areas of tile surface coating material erosion were seen on the base of the left RCS stinger (21:10:09.221UTC), on the base heat shield near the base of the right RCS stinger (21:10:10.425 UTC), on the base heat shield outboard of SSME #2, and near the base of the right OMS nozzle during SSME ignition. (Cameras E17, E18, E19, E20)

No significant movement of the OMS pod tiles during SSME ignition was detected on the STS-105 camera films. (Cameras E17, E18)

The LO2 TSM door appeared to rebound slightly before closing during liftoff. (Camera E20)

SRB ignition was at 21:10:14.029 UTC based on the observation of the PIC firing at LSRB holddown post M-5. (Camera E12)

The left and right SRB GN2 purge lines appeared wrapped, upright, and intact until they were obscured by exhaust plumes at 21:10:16.157 UTC (right purge line) and 21:10:15.829 UTC (left purge line). (Cameras E8, E13)

2.2.4 Ascent Events

Multiple light-orange-colored flares (possibly debris induced) were noted in the SSME exhaust plume during ascent on the long range tracking camera films. Often on previous mission imagery, debris has been seen contacting the SSME exhaust plume resulting in visible flares. Usually this debris was RCS paper. (On STS-26 and STS-101, debris that resulted in very large orange-colored flares was determined to have been tile material.) Examples of flares seen on STS-105 are:

21:10:22.018 UTC: Flare (Camera E224)
21:10:26.677 UTC: Faint, light-colored flare (Camera KTV21A)
21:10:29.606 UTC: Flare seen in the SSME 2 / 3 exhaust plume (Camera E223)
21:10:32.470 UTC: Small, faint flare (Camera E224)
21:10:40.311 UTC: Flare (Camera E224)
21:10:40.313 UTC: Flare (Camera E222)
21:10:55.410 UTC: Small flare (Camera E223)
21:11:00.441 UTC: Flare in SSME #2 exhaust plume (Camera E223)
Camera E207 – Frame 2143: Flare in the SSME exhaust plume.

Body flap motion typical of that seen on previous missions was seen during ascent (frames 1800 to 3200). (Camera E207)

2.3 Onboard Photography of the External Tank (ET-110A)

2.3.1 16mm Umbilical Well Camera Films

One 16 mm umbilical well high speed motion picture film (roll FL101) from the camera with the wide angle (5 mm) lens imaging the SRB and External Tank separation was acquired. Timing data was present on the FL101 umbilical well camera film. (The second 16 mm umbilical well camera with the 10 mm lens (roll FL102) was not flown on STS-105.)

The LSRB separation appeared normal on the 16 mm umbilical well camera film (recorded through the 5mm lens). Numerous light-colored pieces of debris (insulation), and dark debris (charred insulation) were seen throughout the SRB separation film sequence. Typical ablation and charring of the ET/Orbiter LH2 umbilical electric cable tray and the aft surface of the -Y upper strut fairing were seen prior to SRB separation. Numerous irregularly shaped pieces of debris (charred insulation) were noted near the base of the LSRB electric cable tray prior to SRB separation. (A large piece of charred insulation debris was seen coming from behind the base of the electric cable tray on frame 98). Pieces of TPS were seen detaching from the aft surface of the horizontal section of the -Y ET vertical strut. A piece of long, linear-shaped material (probably umbilical purge barrier tape) was seen coming from behind the LH2 umbilical.
Typical blistering of the fire barrier material on the outboard (-Y) side of the LH2 umbilical was seen. The amount of ablation of the TPS on the ET aft dome was typical of previous flights. No anomalies were seen on the left and right SRB nose caps during SRB separation. A large spray of multiple pieces of charred TPS was seen coming from behind the LH2 electric cable tray after SRB separation (frame 930).

The ET separation from the Orbiter appeared normal (although the view was very dark because of the shadow of the Orbiter from the late afternoon Sun). Typical vapor and multiple light-colored pieces of debris were seen after the umbilical separation. No anomalies were noted on the face of the LH2 umbilical after ET separation. As typically seen on previous missions, frozen hydrogen was visible on the orifice of the LH2 17 inch connect. A light-colored area (probably frozen hydrogen) was seen at the two o'clock position from the LH2 umbilical just aft of the cross beam. The separation bolt between the ET and the aft end of the Orbiter (EO-2 fitting near the liquid hydrogen umbilical) was observed to be retracted. The red-colored purge seal on the EO-2 ball joint fitting appeared to be in place. A line of light-colored marks on the ET aft dome just aft of the crossbeam was confirmed to have been present on the pre-launch closeout photography. A large, light-colored area was seen on the TPS of the LO2 feedline aft of the crossbeam that may have been an effect of the lighting or possibly an area of TPS erosion. A small area of possible TPS erosion was seen on the –Y thrust strut. The LH2 tank TPS appeared to be in good condition on the 16mm camera view. Typical of previous missions, a dark-colored mark was seen extending diagonally across the ET intertank from near the –Y leg of the forward bipod toward the LSRB forward attach (probably due to aeroheating or the SRB separation motor firing). The LSRB separation burn scar on the forward –Y axis of the ET appeared normal. Very faint light-colored marks were seen on the –Y ET thrust panel. However, it could not be confirmed whether or not these marks were divots because of the limited resolution due to the curvature of the ET and the view perspective.

2.3.2 35mm Umbilical Well Camera Film (Roll 384)

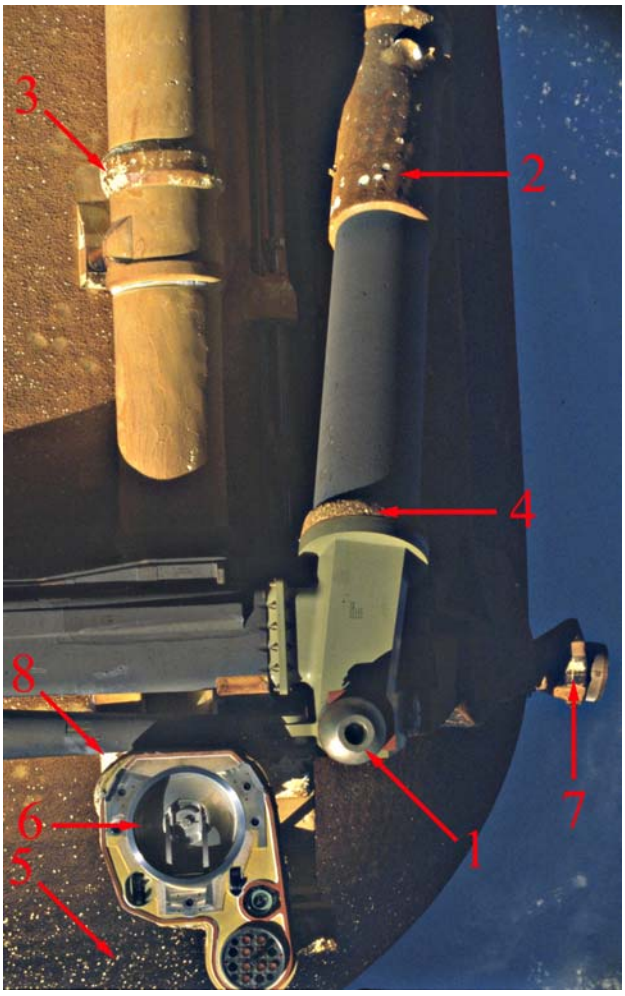


Figure 2.3.2 (A) View of the Aft ET (frame 10)

The separation bolt between the ET and the aft end of the Orbiter (EO-3 fitting near the liquid oxygen umbilical) was observed to be retracted and not protruding. See Figure 2.3.2 (A), annotation 1. (The EO-3 bolt was seen to be protruding on STS-106, STS-102, and STS-100 umbilical well camera films. A Shuttle Program investigation of the STS-106 bolt extension was previously conducted in October, 2000).

Multiple divots and erosion marks (approximately twelve in number) were visible near the forward end of the +Y thrust strut. See Figure 2.3.2 (A), annotation 2.

Minor TPS erosion and very small divots (typical of previous missions) were seen on all of the LO2 feedline flanges. See Figure 2.3.2 (A), annotation 3. TPS abrasion marks were also seen on a small bracket near the aft LO2 feedline flange forward of the ET crossbeam. Small, shallow areas of TPS erosion and divoting were visible on the aft flange of the +Y ET/Orbiter thrust strut. See Figure 2.3.2 (A), annotation 4. Typical ablation and divoting of the TPS on the vertical section of the +Y electric cable tray adjacent to the LO2 umbilical were detected. Small

"popcorn" divots, typical of previous mission views, were seen on the ET aft dome. See Figure 2.3.2 (A), annotation 5.

The face of the LO2 umbilical carrier plate appeared to be in excellent condition (no indication of damaged or missing lightning contact strips was detected). See Figure 2.3.2 (A), annotation 6.

The red-colored purge seal on the EO-3 ball joint fitting was in place.

An area of possible TPS erosion was seen on the aft ET / RSRB attach. See Figure 2.3.2 (A), annotation 7.

A triangular-shaped, light-colored area was seen on the TPS adjacent to the 11 o'clock position of the LO2 umbilical face (just aft of the crossbeam). It was not determined if this was an area of possible TPS erosion or an effect of the lighting on the –Y side of the LO2 umbilical. See Figure 2.3.2 (A), annotation 8.

As typically seen, multiple very small "popcorn" divots were seen on the LH2 tank TPS forward of the ET crossbeam.

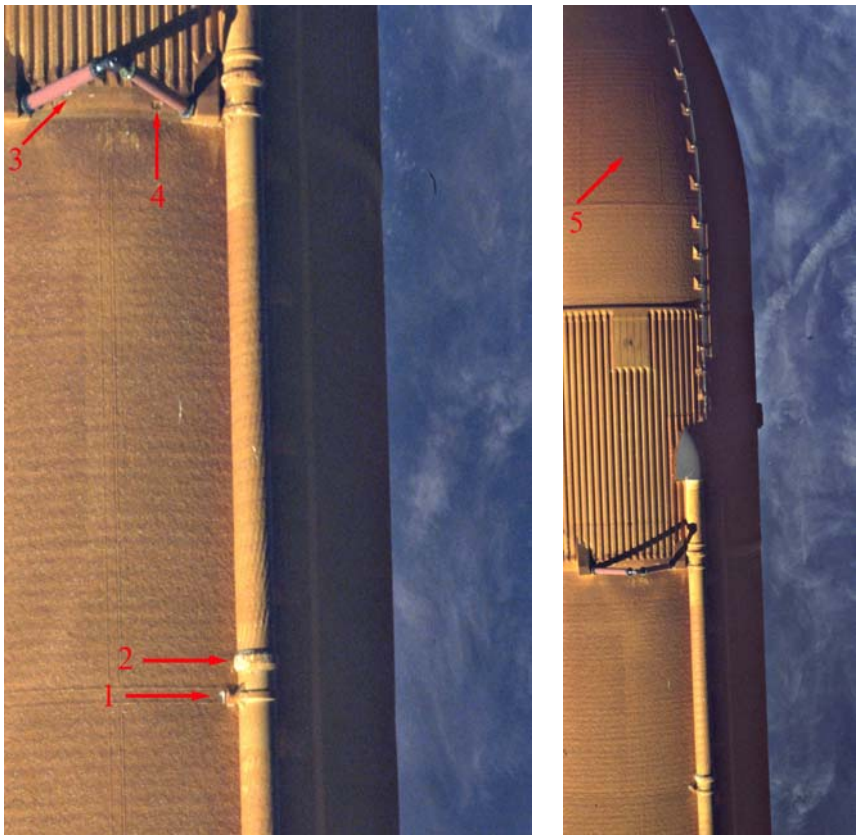


Figure 2.3.2 (B) Views of the Forward ET (frames 45 and 58)

An approximately six inch long, white-colored divot was seen on the LH2 tank TPS next to the –Y side of the first LO2 feedline flange aft of the forward bipod (station 1377 X_T). No exposed substrate material was noted. See Figure 2.3.2 (B) annotation 1. Abrasion of the LO2 feedline flange aft of the bipod was visible. See Figure 2.3.2 (B) annotation 2.

Two small, white-colored divots were seen on the LH2 tank-to-intertank closeout flange under the –Y leg of the forward bipod. See Figure 2.3.2 (B), annotation 3. Both of the jack pad closeouts on the LH2 tank-to-intertank closeout flange beneath the forward bipod appeared to be intact. See Figure 2.3.2 (B), annotation 4.

Typical of previous missions, a few very small white-colored marks (divots) were seen on and between the intertank stringer heads.

The visible portion of the LO2 tank / Ojive TPS appeared to be in excellent condition. See Figure 2.3.2 (B), annotation 5. The tip of the ET nose was not imaged. The aero friction and aero heating marks normally seen on the TPS just aft of the nose cone were not visible because of shadows.

Notes: Shadows from the back lighting from the late afternoon Sun limited the 35 mm umbilical camera views in the +Y direction of the ET LO2 feedline. The +Z / +Y ET Thrust Panel TPS was obscured by shadow and could not be analyzed. Also, the +Z / -Y ET TPS was not visible because of the view of the camera. The –Y ET thrust panel was not in view on the 35mm umbilical well camera film. Sixty frames imaging the ET were acquired. The images were excellent quality except for the areas obscured by shadow. The +X translation maneuver was performed on STS-105 to facilitate the imaging of the ET with the umbilical well cameras.

2.3.3 ET Handheld Photography

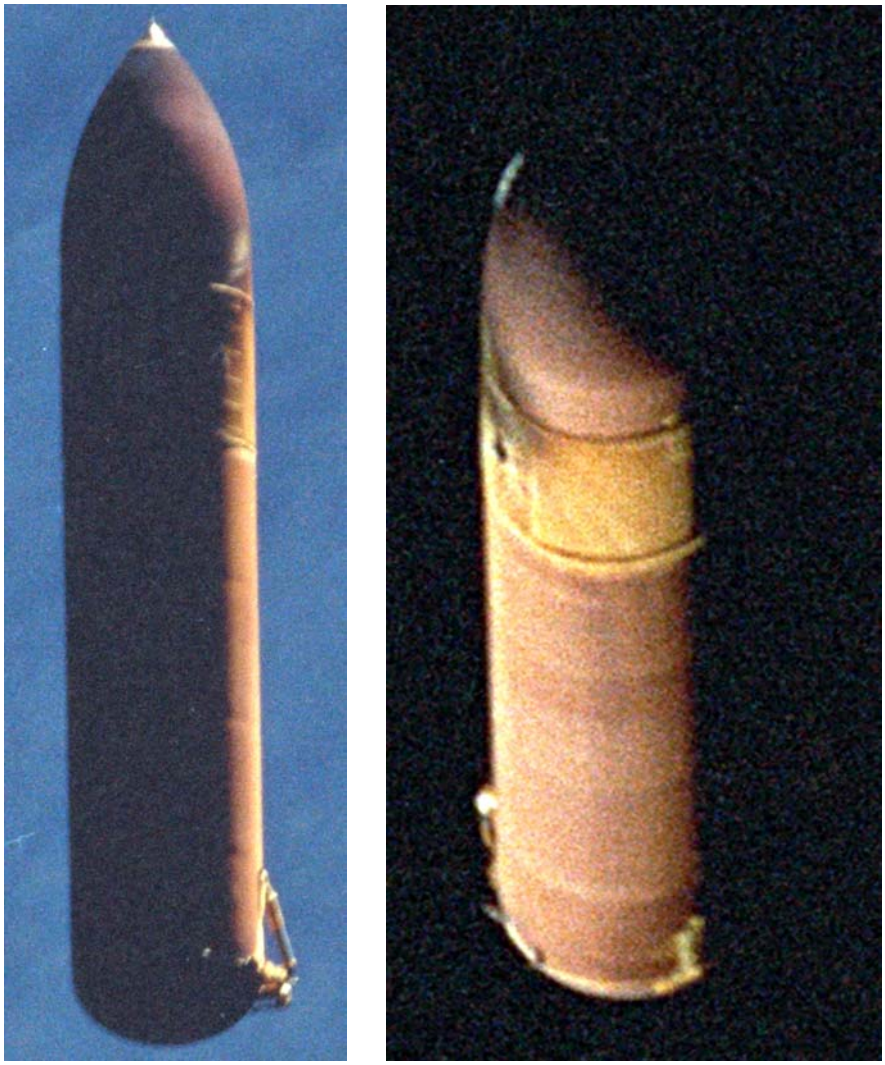


Figure 2.3.3 Crew Handheld Images of the External Tank (frames 6 and 13)

35 mm Crew Handheld Film (Roll 301)

No anomalous or unusual observations were noted on the handheld film views. Views of the -Y, -Z sides of the ET, and the ET aft dome were acquired. Extensive shadows from the late afternoon Sun hindered the analysis of the handheld ET film.

The distance of the ET was calculated to be approximately 2 km on the first photographic frame acquired. A total of thirteen pictures of the ET were obtained using the handheld Nikon F5 camera with a 400 mm lens before the ET crossed the Sunset terminator. Timing data is present on the film. The first picture was taken at approximately 15 minutes MET. The astronauts performed a manual pitch maneuver from the heads-up position to bring the ET into view in the Orbiter overhead windows for the handheld video and photography.

2.3.4 ET Handheld Video

Several minutes of video imaging the External Tank using the new PD-100 camcorder was acquired commencing at approximately 14.5 minutes MET. The views were of the –Y / -Z side of the ET. Shadows due to the late afternoon Sun and the exposure of the ET limited the viewing of the ET surface features. No anomalous or unusual observations were noted on the video views. No venting from the ET intertank gaseous hydrogen vent or the aft ET umbilicals was seen on the STS-105 video.

2.4 Landing Events Timing

The time codes from videos were used to identify specific events during the screening process. The landing event times are provided in Table 2.4.

Event Description	Time (UTC)	Camera
Left main gear door opening	234:18:22:39.304	KTV33L
Right main gear door opening	234:18:22:39.504	KTV33L
Nose gear door opening	~234:18:22:39.311	ET207
Left main gear tire touchdown	234:18:22:58.381	SLF North
Right main gear tire touchdown	234:18:22:58.414	SLF North
Drag chute initiation	234:18:23:01.323	KTV33L
Pilot chute at full inflation	234:18:23:02.293	KTV33L
Bag release	234:18:23:02.514	KTV11L
Drag chute inflation in reefed configuration	234:18:23:03.928	KTV33L
Drag chute inflation in disreefed configuration	234:18:23:07.432	KTV33L
Nose gear tire touchdown	234:18:23:09.197	KTV33L
Drag chute release	234:18:23:42.554	KTV11L
Wheel Stop	234:18:24:04.108	KTV11L

Note: ~ Denotes that the time shown is approximate.

Table 2.4 Landing Event Times

2.5 Landing Sink Rate Analysis

Image data from the centerline camera at the approach end of runway 15 was used to determine the landing sink rate of the main gear. In the analysis, data from approximately one second of imagery immediately prior to touch down for each of the landing gear was considered. Data

points defining the main gear struts were collected on every frame (100 frames of data during the last second prior to touch down with respect to each landing gear). An assumption was made that the line of sight of the camera was perpendicular to the Orbiter's y-axis. The distance between the main gear struts (272 inches) was used as a scaling factor. The main gear midpoint height above the runway was calculated by the change in vertical difference between the main gear struts and the reference point on the runway. Trendlines for the main gear midpoint were determined considering the height of the Orbiter above ground with respect to time. Sink rate equals the slope of each regression line.

The main gear sink rate for the STS-105 landing at one second, at half a second, and at a one quarter of a second are provided in Table 2.5.

Time Prior to Touchdown	Main Gear Midpoint Sink Rate	Estimated Error (1σ)
1.00 Sec.	4.3 ft/sec	± 0.1 ft/sec
0.50 Sec.	3.1 ft/sec	± 0.1 ft/sec
0.25 Sec.	2.1 ft/sec	± 0.2 ft/sec

Table 2.5 Main Gear Midpoint Landing Sink Rate

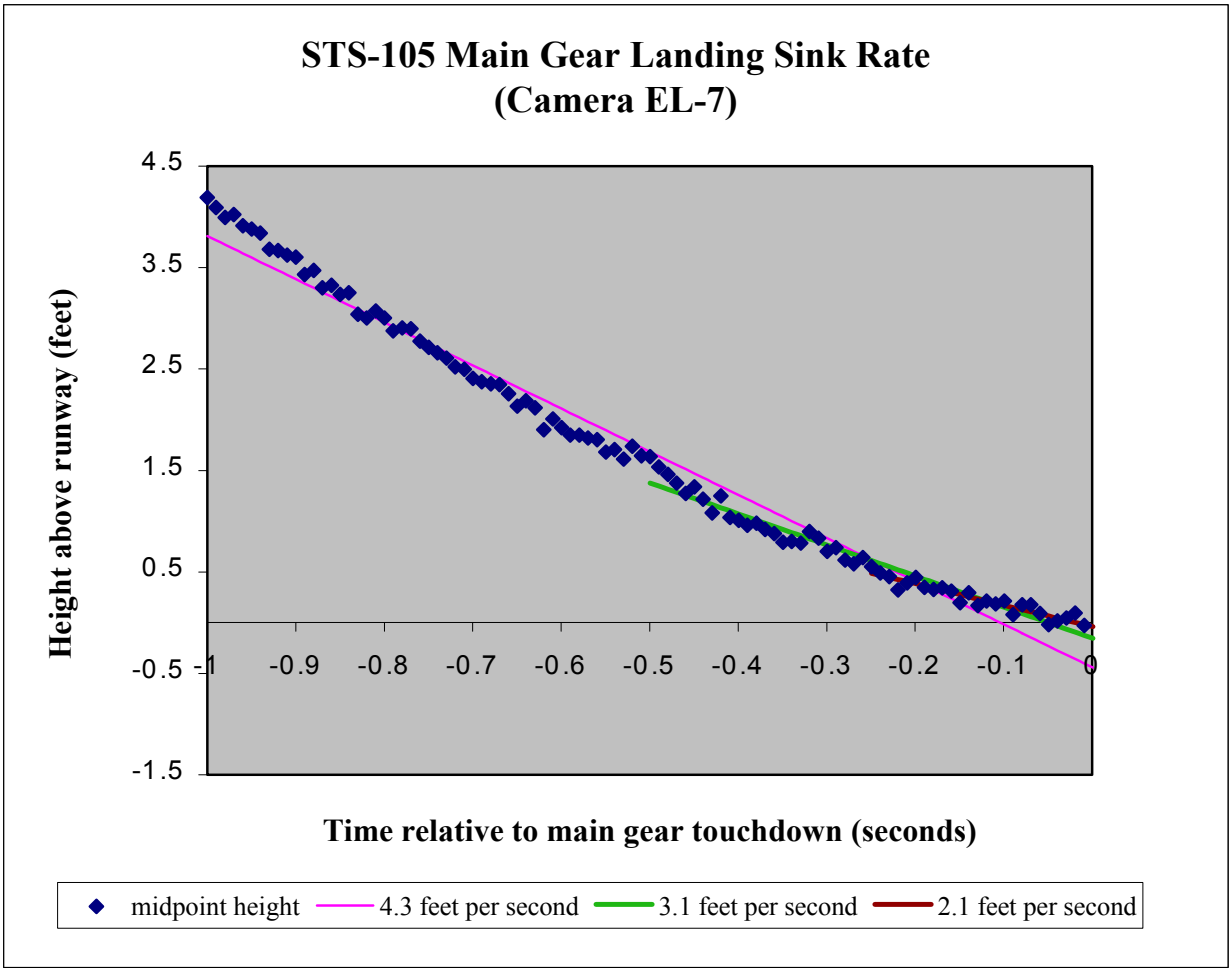


Figure 2.5 Main Gear Midpoint Landing Sink Rate

The maximum allowable main gear sink rate values are 9.6 feet / second for a 212,000 lb. vehicle and 6.0 feet/second for a 240,000 lb. vehicle. The landing weight of the STS-105 vehicle was reported to be 222,275 lbs.

2.6 Other

2.6.1 Normal Events

Normal events observed included:

- elevon and body flap motion prior to liftoff
- RCS paper debris from SSME ignition through liftoff
- ET twang
- Vapor and ice during GH2 vent arm retraction

- ice and vapor from the LO2 and LH2 TSM T-0 umbilical prior to and / after disconnect
- multiple pieces of ET/Orbiter umbilical ice debris falling along the body flap during liftoff
- vapor off the SRB stiffener rings
- acoustic waves in the exhaust cloud during liftoff
- debris in the exhaust cloud (including water baffle material) after liftoff
- charring of the ET aft dome after liftoff
- ET aft dome outgassing
- roll maneuver
- expansion waves
- condensation around the launch vehicle during ascent (including vapor trails off the Orbiter wing tips)
- linear optical effects
- recirculation
- SRB plume brightening
- SRB slag debris before, during, and after SRB separation

2.6.2 Normal Pad Events

Normal pad events observed included:

- hydrogen burn ignitor operation
- FSS and MLP deluge water activation
- sound suppression system water operation
- GH2 vent arm retraction
- TSM T-0 umbilical disconnect and retraction
- LH2 and LO2 TSM door closures

APPENDIX B. MSFC PHOTOGRAPHIC ANALYSIS SUMMARY

The MSFC Report can be accessed on their Engineering Photographic Analysis website at https://photo4.msfc.nasa.gov/.

Space Shuttle Mission STS-105

Engineering Photographic Analysis Summary Report
Marshall Space Flight Center

T. J. Rieckhoff (NASA/MSFC)
M. Covan (USA)
J.M. O'Farrell (USA)
D.H. Osborne (ERC)

September 11, 2001
Marshall Space Flight Center,
Huntsville, AL 35812

Contents

Figures

Engineering Photographic Analysis Report for STS-105

Launch of the one-hundred-sixth Space Shuttle mission, STS-105, thirtieth flight of the Orbiter Discovery (OV-103), occurred August 10, 2001 at 4:14PM CDT from launch complex 39-A, Kennedy Space Center (KSC), Florida. Launch time is reported as 01:222:21:10:14.019 Universal Coordinated Time (UTC) by the MSFC Flight Evaluation Team.

STS-105 Photographic Analysis Summary:

One significant item was observed on launch film and/or video products covering Space Shuttle mission, STS-105. This item was included in the Launch+4 Day "CONSOLIDATED FILM REVIEW REPORT" by KSC, JSC, MSFC Film/Video Analysis Teams, 15 August 2001 - CFVR-105-01.

Camera: E18 Time: GMT 21:10:15.643

An unidentified, thin, cylindrical-shaped piece of debris was seen falling near the LH2 TSM T0 umbilical disconnect and past the left RCS stinger during liftoff. The first appearance on film is approximately 1.5 seconds after T0. The item's origin is unknown. It appears light-colored on one end and red-brown color on the other end. As the item falls and tumbles, it maintains a cylindrical shape.

Photographic Analysis Website:

Further information concerning photographic analysis of this and previous space shuttle missions is available on the MSFC Engineering Photographic Analysis website at URL:

http://photo4.msfc.nasa.gov/STS/sts105/sts105.html

Information available on the MSFC Engineering Photographic Analysis website includes:

- Photographic Acquisition Disposition Document (PADD),
- Individual camera status and assessments,
- Annotated images of notable observations,
- Movies of select events, and
- Photographic Analysis Mission Summary Report (PDF format).

Photographic Coverage:

Photographic and video coverage has been evaluated to determine proper operation of the flight hardware. Video and high-speed film cameras providing this coverage are located on the fixed service structure (FSS), mobile launch platform (MLP), perimeter sites, Eastern Test Range tracking sites and onboard the vehicle.

Sixty-seven engineering photographic products consisting of launch video, ground-based engineering films and onboard film were received and reviewed at MSFC. Camera coverage received at MSFC for STS-105 is illustrated in the following table.

	16mm	35mm	Video
MLP	19	0	4
FSS	5	0	3
Perimeter	0	7	5
Tracking	0	9	11
Onboard	1	2	1
Other	0	0	0
Totals	25	18	24

No video was received from video camera OTV048. IRIG Timing was not available on several video cameras: ET205, ET207, ET212, and ET213. Video from camera OTV041 was somewhat overexposed due to the sun angle.

No film was received from film camera E205. Film camera E223 experienced excessive vibration and bounce. Video camera TV7B does not track the vehicle as planned and film camera E220 experienced erratic tracking. Film camera E33 does not image the GUCP as planned. Film cameras E54 and E59 do not image the vehicle as planned. The image was not centered in frame on film camera E54.

T-Zero Times :

T-Zero times are regularly determined from MLP cameras that view the SRB Holddown posts, without doghouse covers, M-1, M-2, M-5, and M-6. These cameras, listed below with their corresponding Holddown Post, record the explosive bolt combustion products.

Holddown Post	Camera	Time (UTC)
M-1	E9	222:21:10:14.028
M-2	E8	222:21:10:14.029
M-5	E12	222:21:10:14.027
M-6	E13	222:21:10:14.028

SRB Separation Timing:

SRB separation time, as recorded by observations of the BSM combustion products from long-range film camera E207, occurred at 222:21:12:15.947 UTC.

Anomalies:

No anomalous events or significant problems were noted on this mission.

Observations:

Video Camera OTV061: Frost on ET Nose Cap Louvers

Frost was observed on the External Tank Nose Cap Louvers prior to liftoff.

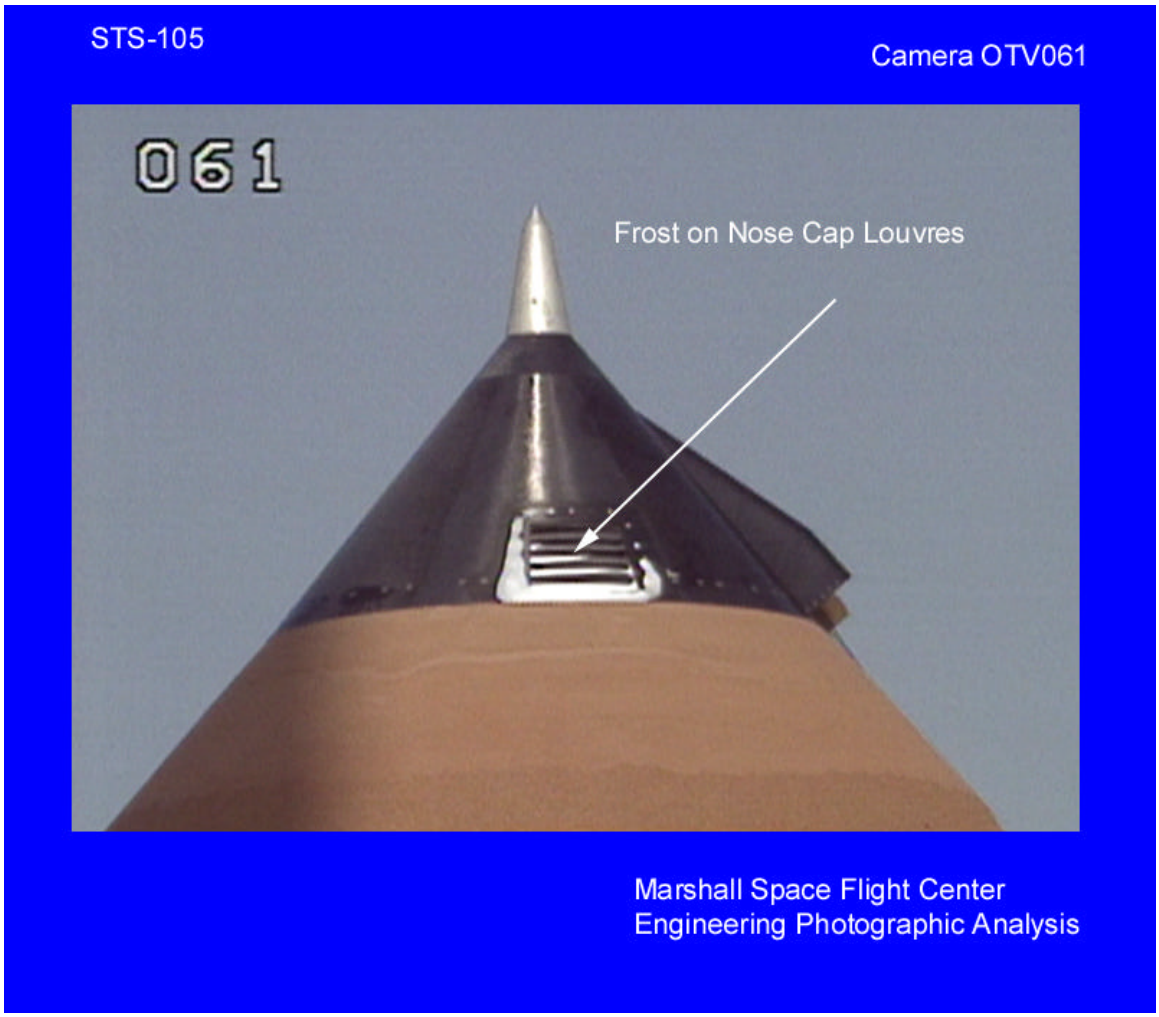


Figure 1. Frost on ET Nose Cap Louvers

Film Camera E2: Streaks in SSME #1 Plumes

Several engine streaks were observed in SSME#1 plume prior to launch. Timing for these streaks: 222:21:10:11.296 UTC, 222:21:10:12.514 UTC, 222:21:10:13.140 UTC and 222:21:10:14.728 UTC. The duration of the streaks was approximately one frame or 1/400 sec. Engine streaks of this short duration are common occurrences, seen on many previous missions.

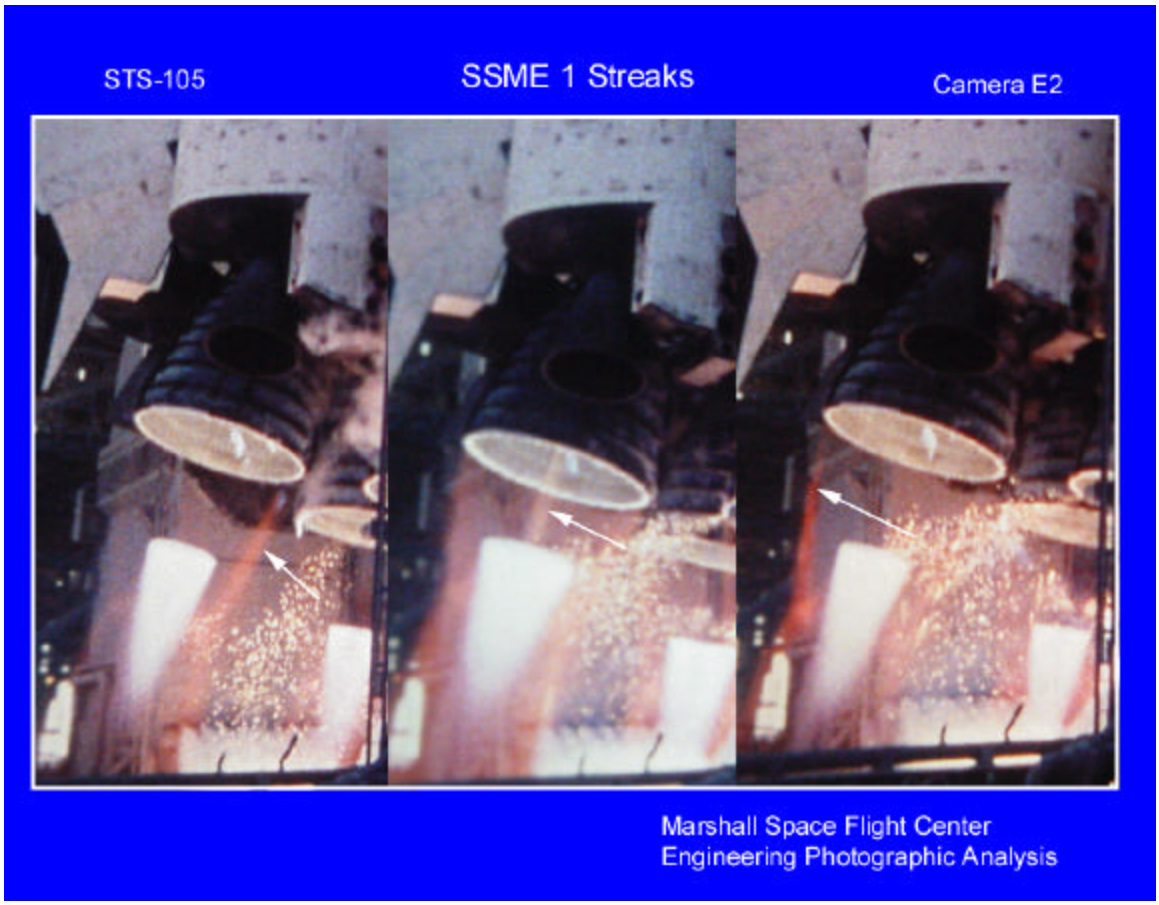


Figure 2. Streaks in SSME #1 Plumes

Film Camera E19: Streaks in SSME #3 Plumes

Several streaks were also observed in SSME#3 plumes prior to launch. Timing for these streaks: 222:21:10:12.078 UTC, and 222:21:10:13.380 UTC.

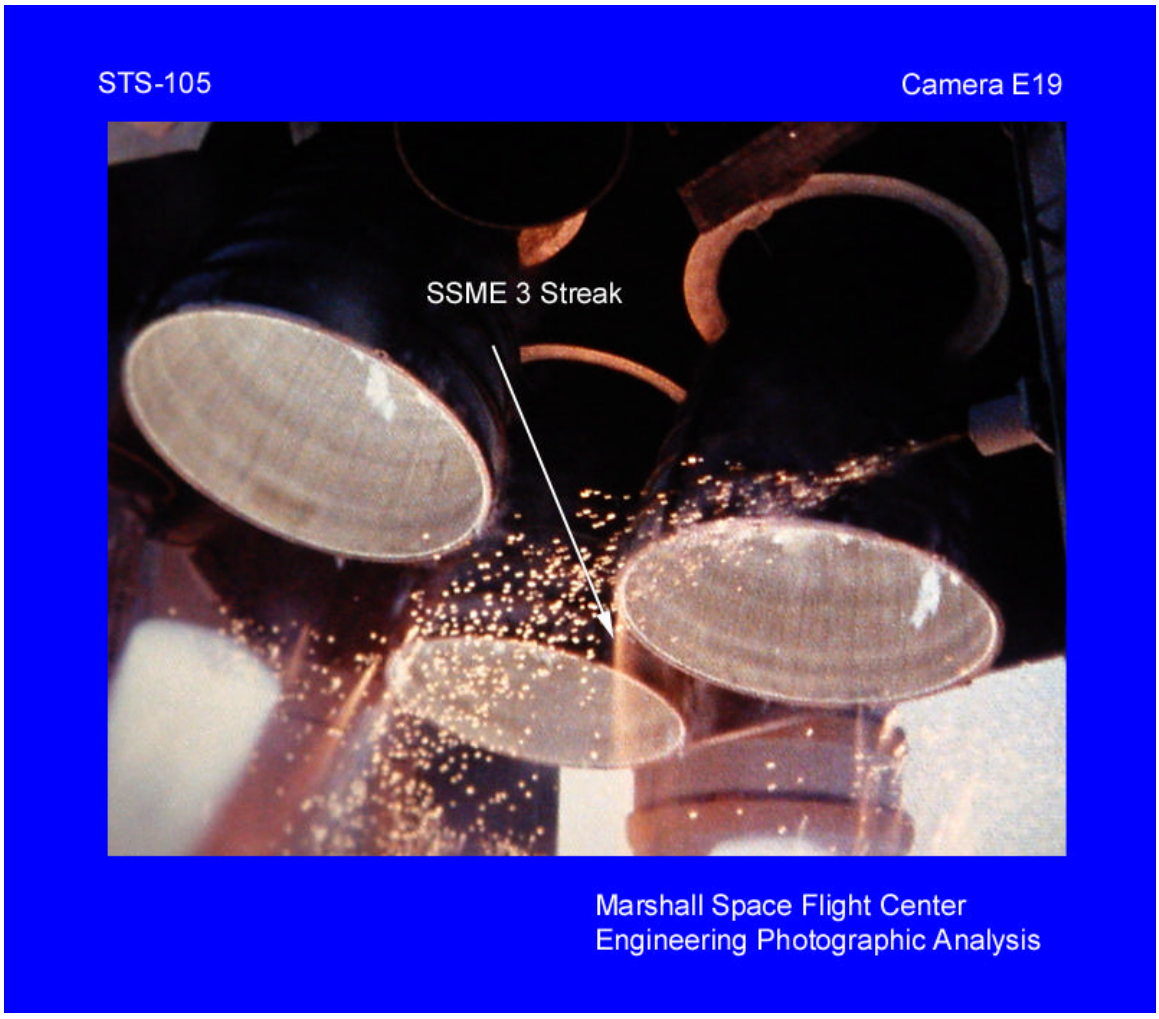


Figure 3. Streaks in SSME #3 Plumes

Film Camera E19: Chipped Tile on Right Stinger Pod

A chipped tile was observed on the Right Stinger Pod.

Figure 4. Chipped Tile on Right Stinger Pod

Film Camera E19: Bright Areas on SSME#3 Hot Wall

Several bright areas were observed on the hot wall of SSME #3 nozzle. Bright areas on SSME hot walls have been observed previously.

Figure 5. Bright Areas on SSME#3 Hot Wall

Film Camera E31: Dark-colored debris Falls from FSS prior to Liftoff

Dark colored debris fell from the Fixed Service Structure prior to Liftoff.

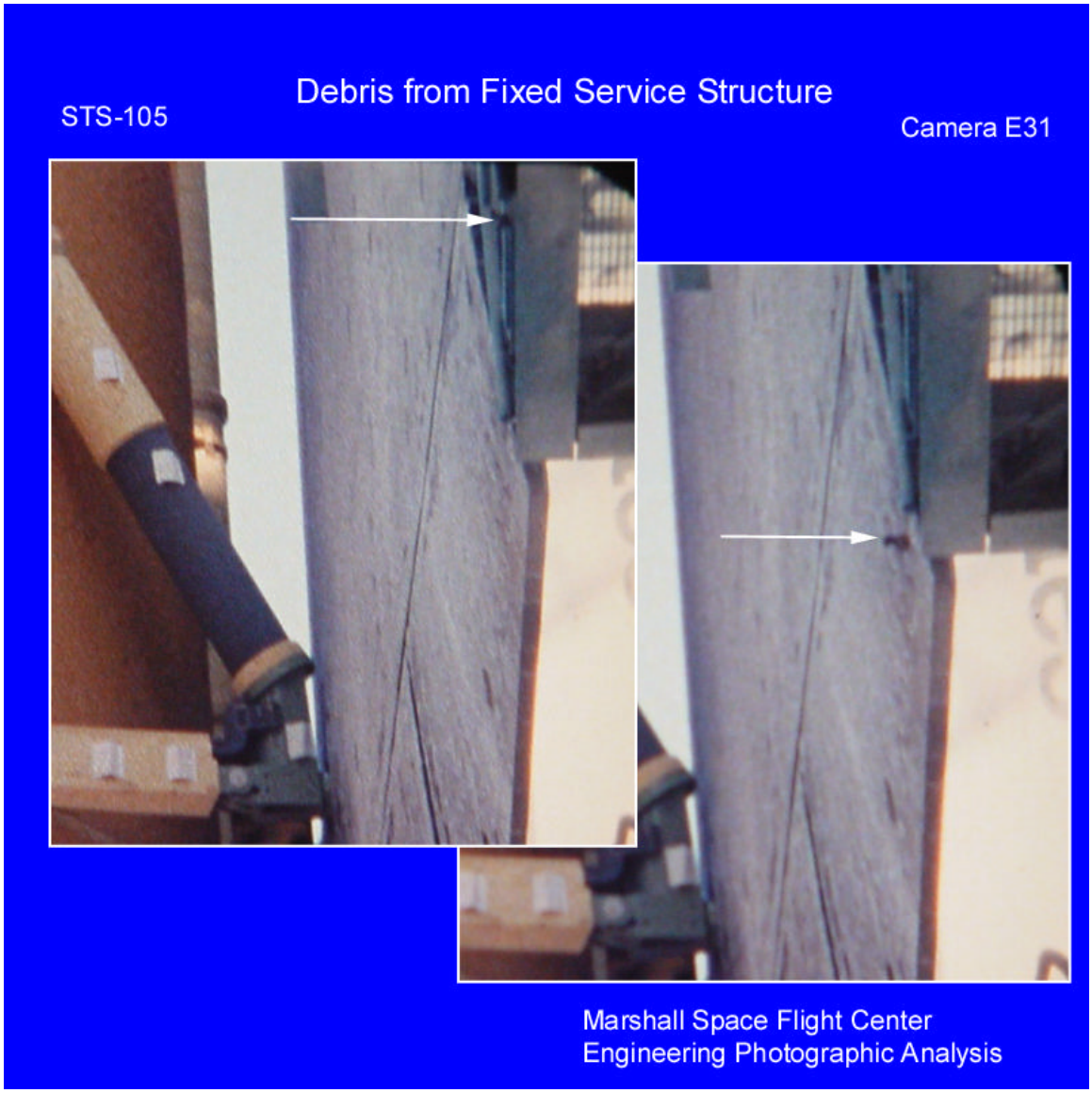


Figure 6. Dark-colored debris Falls from FSS prior to Liftoff

Film Camera E34: Orbiter Tile Coloration Change

A tile on the –Z side of the left Orbiter wing appeared to change coloration, most likely from lighting changes on the tile as the Orbiter lifts off the pad. This coloration change is considered noteworthy

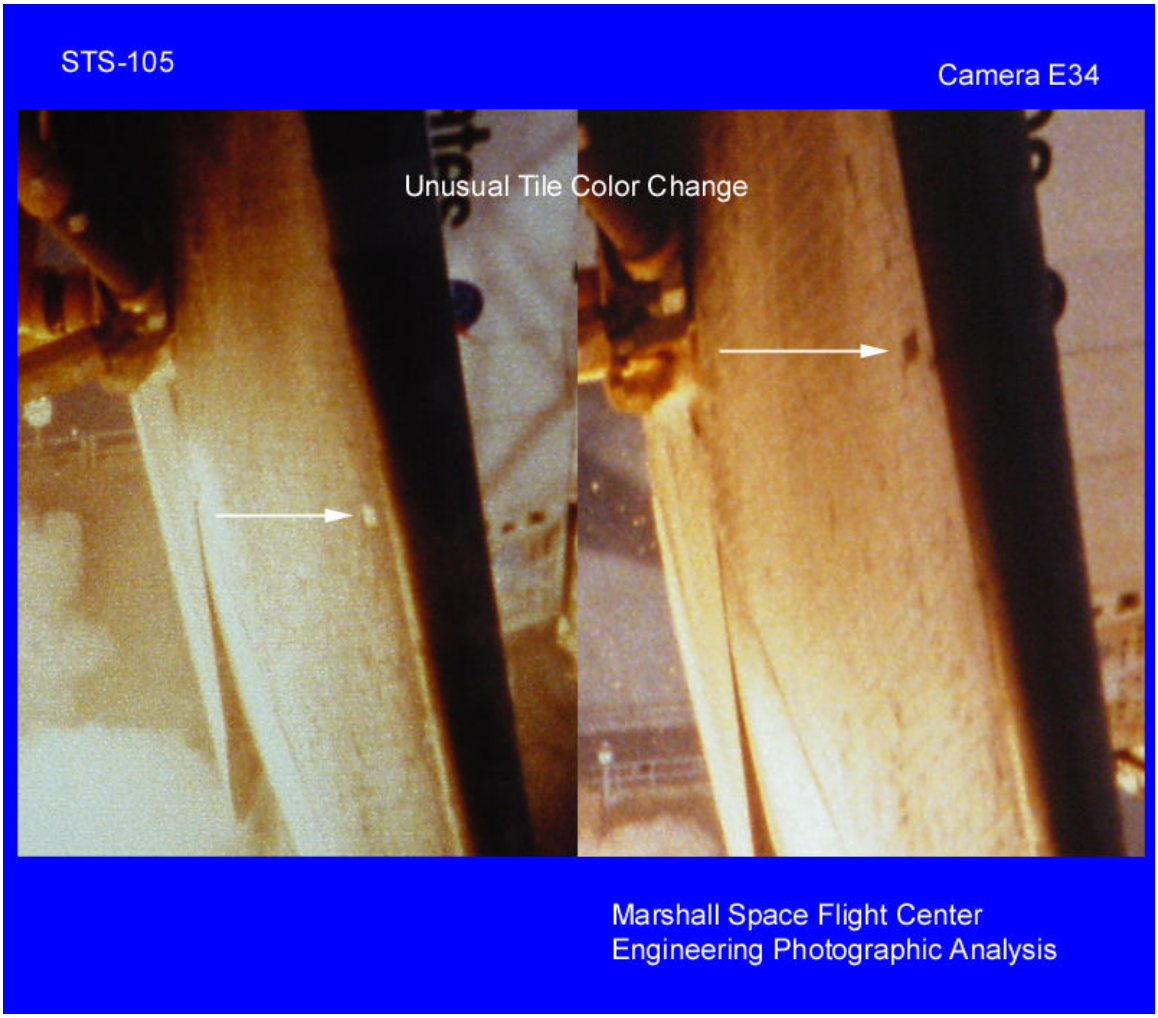


Figure 7. Orbiter Tile Coloration Change

Film Camera E12: Rectangular Shaped Debris near SRB at Liftoff

A rectangular shaped debris object was noted in the vicinity of the SRB aft skirt at liftoff. Film camera E12 view SRB Holdown Post M-5 during ignition and liftoff.

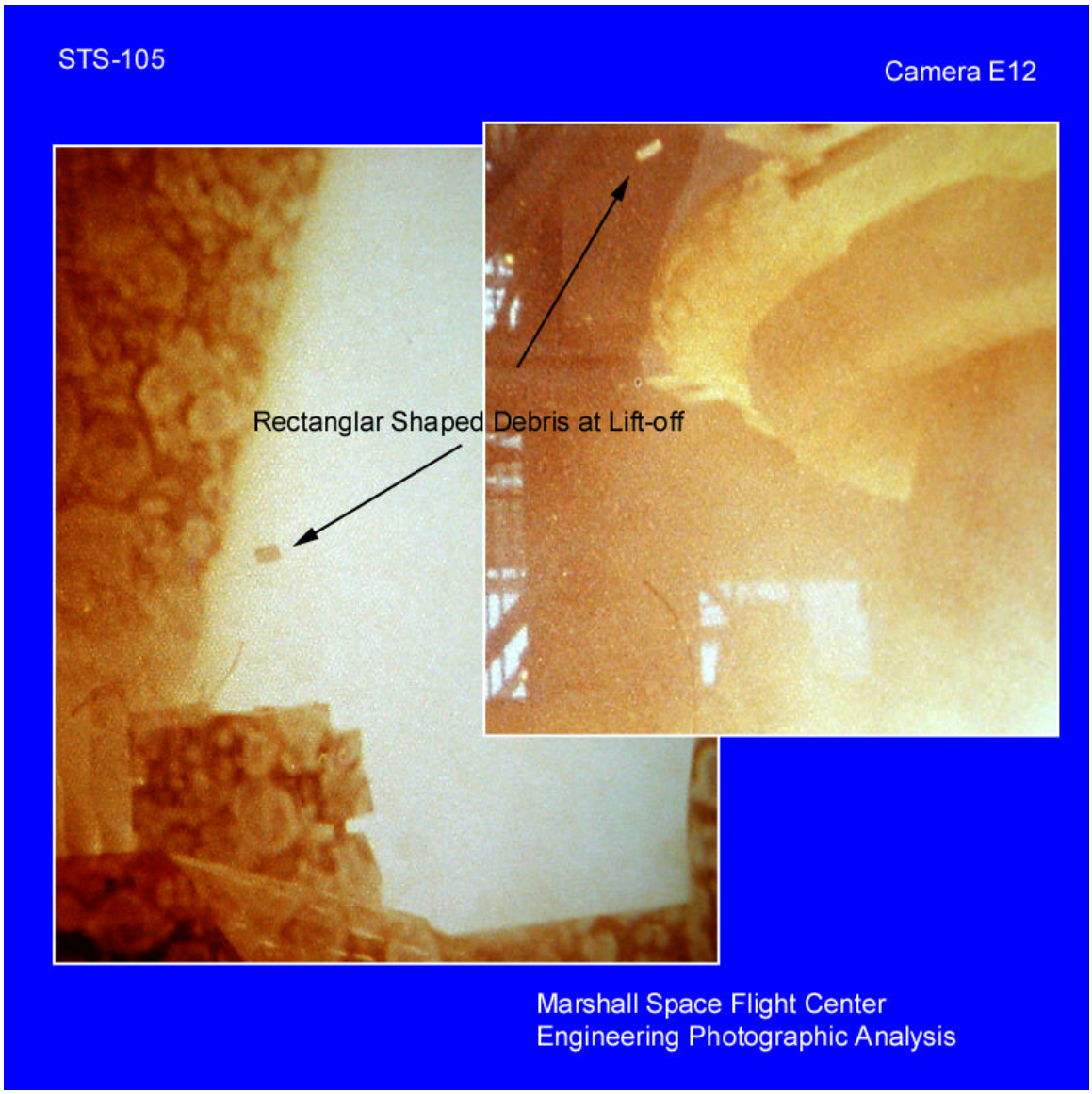


Figure 8. Rectangular Shaped Debris near SRB at Liftoff

Film Camera E18: Cylindrical Debris Item

An unidentified, thin, cylindrical-shaped piece of debris was seen falling near the LH2 TSM T0 umbilical disconnect and past the left RCS stinger during liftoff. The first appearance on film is approximately 1.5 seconds after T0. The item's origin is unknown. It appears light-colored on one end and red-brown color on the other end. As the item falls and tumbles, it maintains a cylindrical shape.

This observation was listed in the STS-105 Launch+4 Day "CONSOLIDATED FILM REVIEW REPORT" by the KSC, JSC, MSFC Film/Video Analysis Teams released on 15 August 2001.

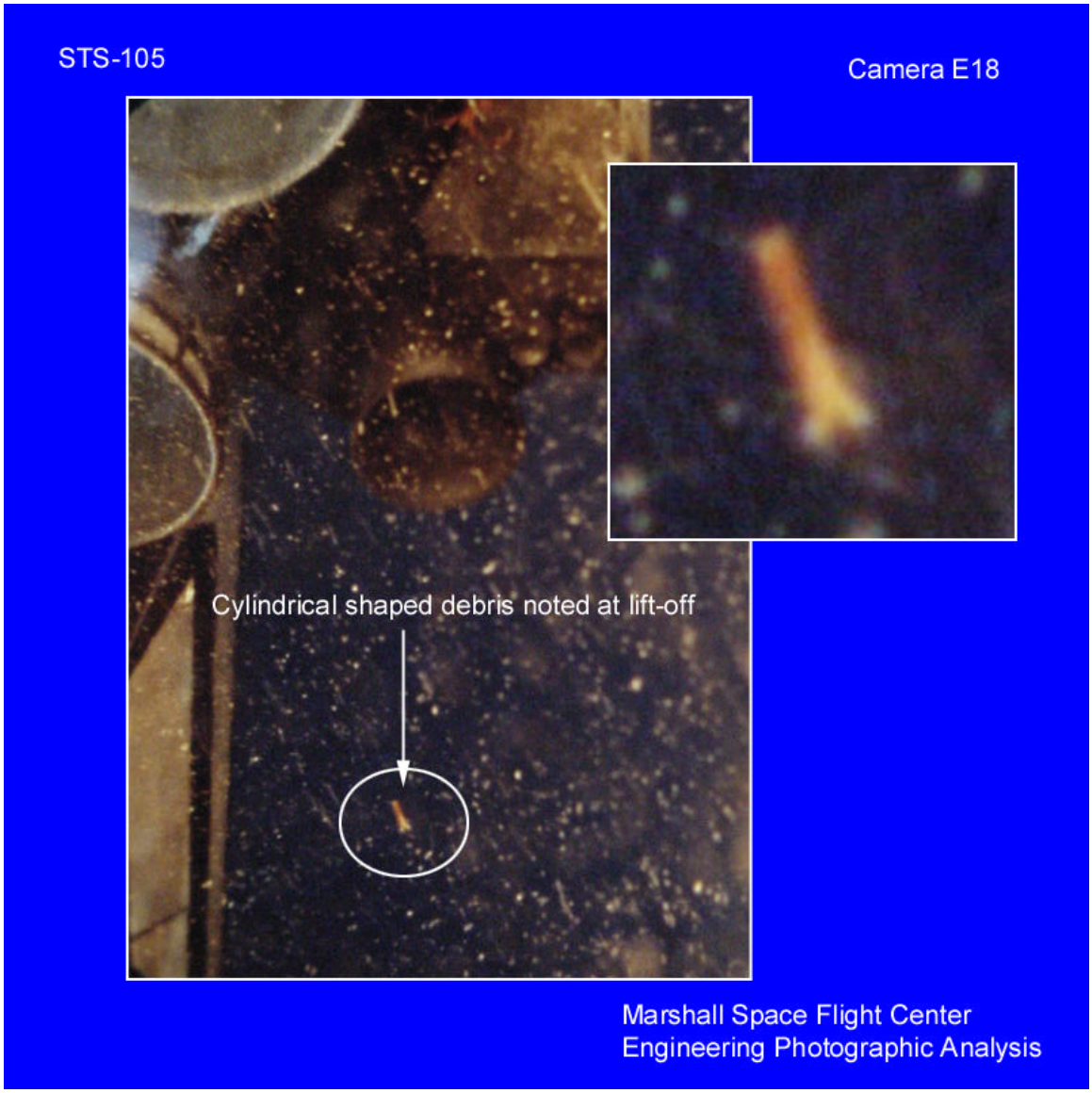


Figure 9. Cylindrical Debris Item

Film Camera E54: Bright Object near Right Wing of Orbiter

A bright object was noted near the right wing of the Orbiter during ascent. A small gray-colored object is noted on the inserts, from the frame just prior to the change in illumination in the object and in approximately the same location.

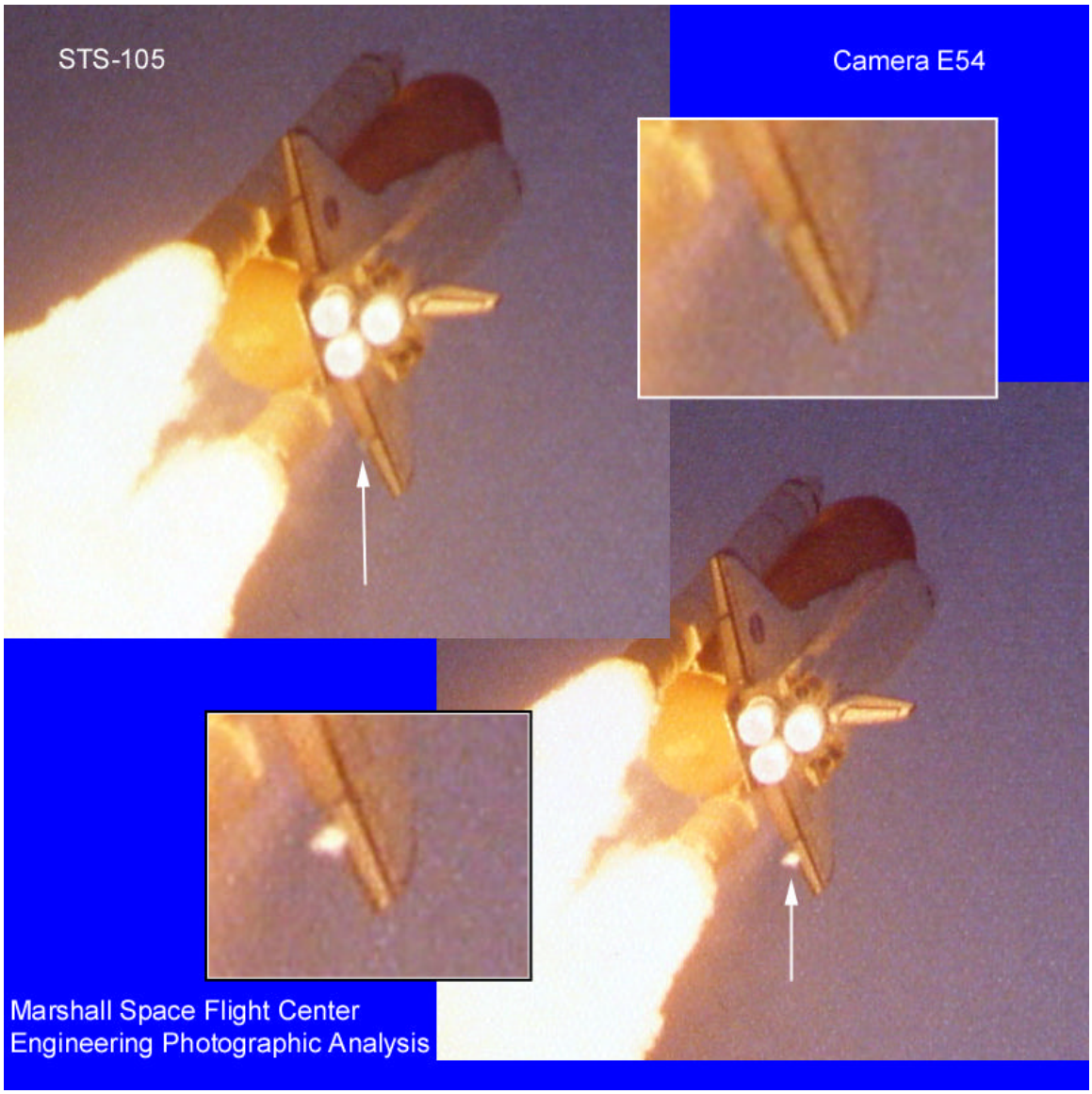


Figure 10. Bright Object near Right Wing of Orbiter

Film Camera E207: Brown-colored Debris on –Z side of Vehicle

Brown-colored debris was observed, by film camera E-207 ,on the –Z side falling away from the vehicle during ascent.

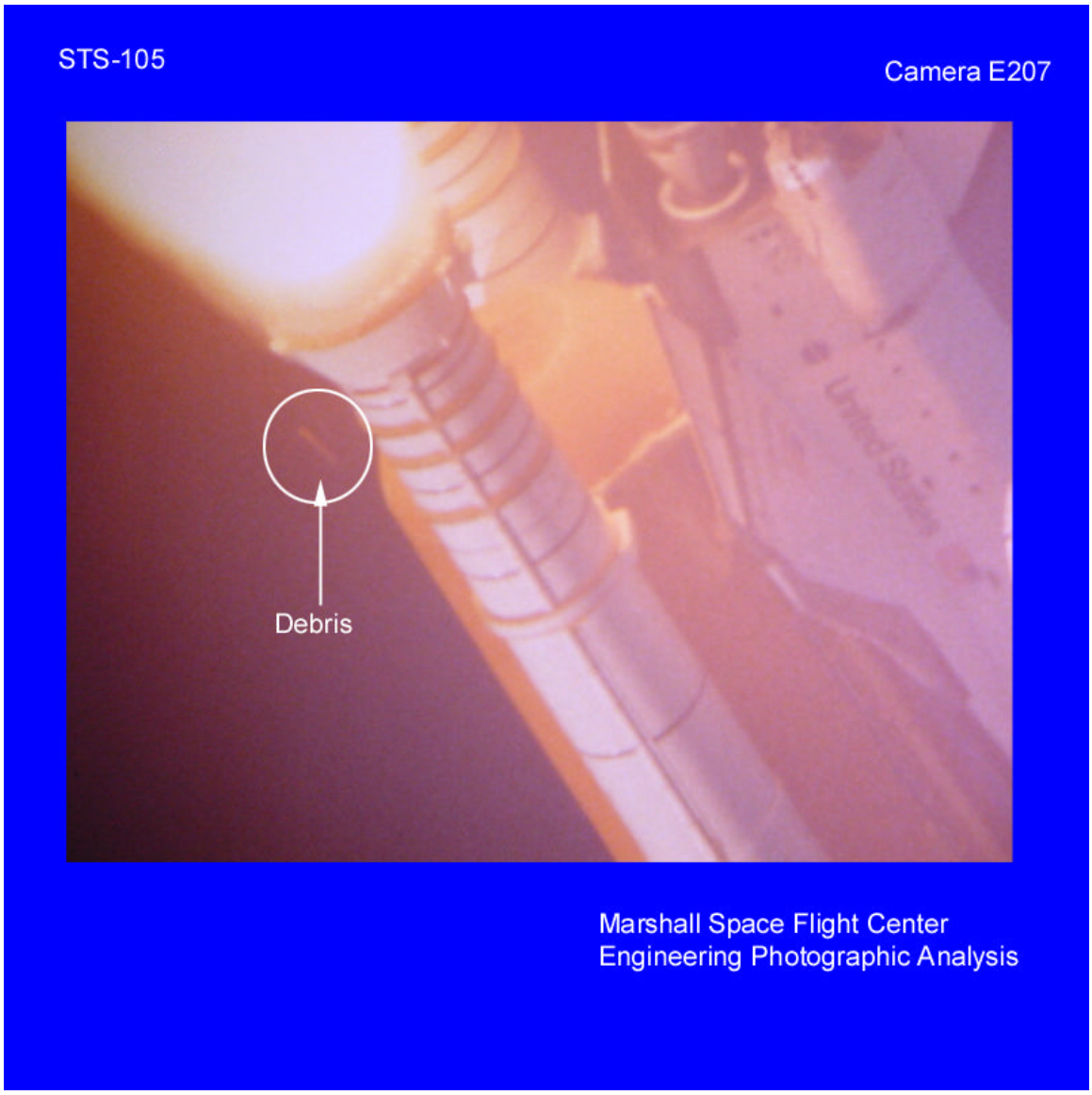


Figure 11. Camera E-207: Brown-colored Debris on –Z Side of Vehicle

Film Camera E220: Brown-colored debris on –Z side of Vehicle

The debris in this image was observed by film camera E220. It is likely the same debris as that observed by film camera E-207 in Figure 11, on the –Z side falling away from the vehicle during ascent.

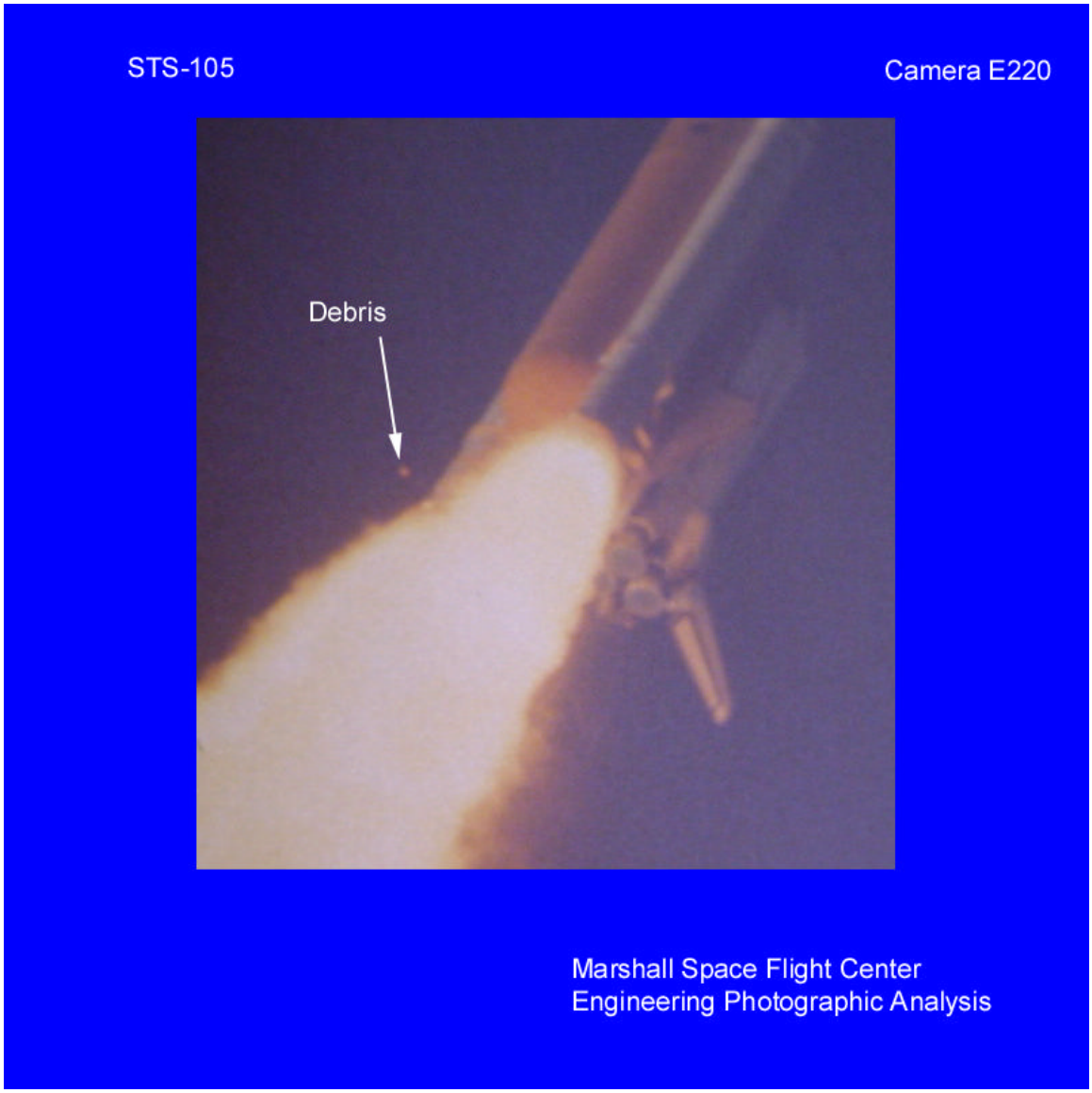


Figure 12. Camera E220: Brown-colored Debris on –Z Side of Vehicle

Film Camera E223: Debris Ejected from SRB Plumes

Numerous pieces of debris were noted, from Film camera E223, as they were ejected from the SRB plumes. This event occurred at approximately 222:21:11:22.305 UTC.

Figure 13. Debris Ejected from SRB Plumes

Video Camera ET207: Debris Ejected from SRB Plume

Debris ejected from the SRB plume was observed.

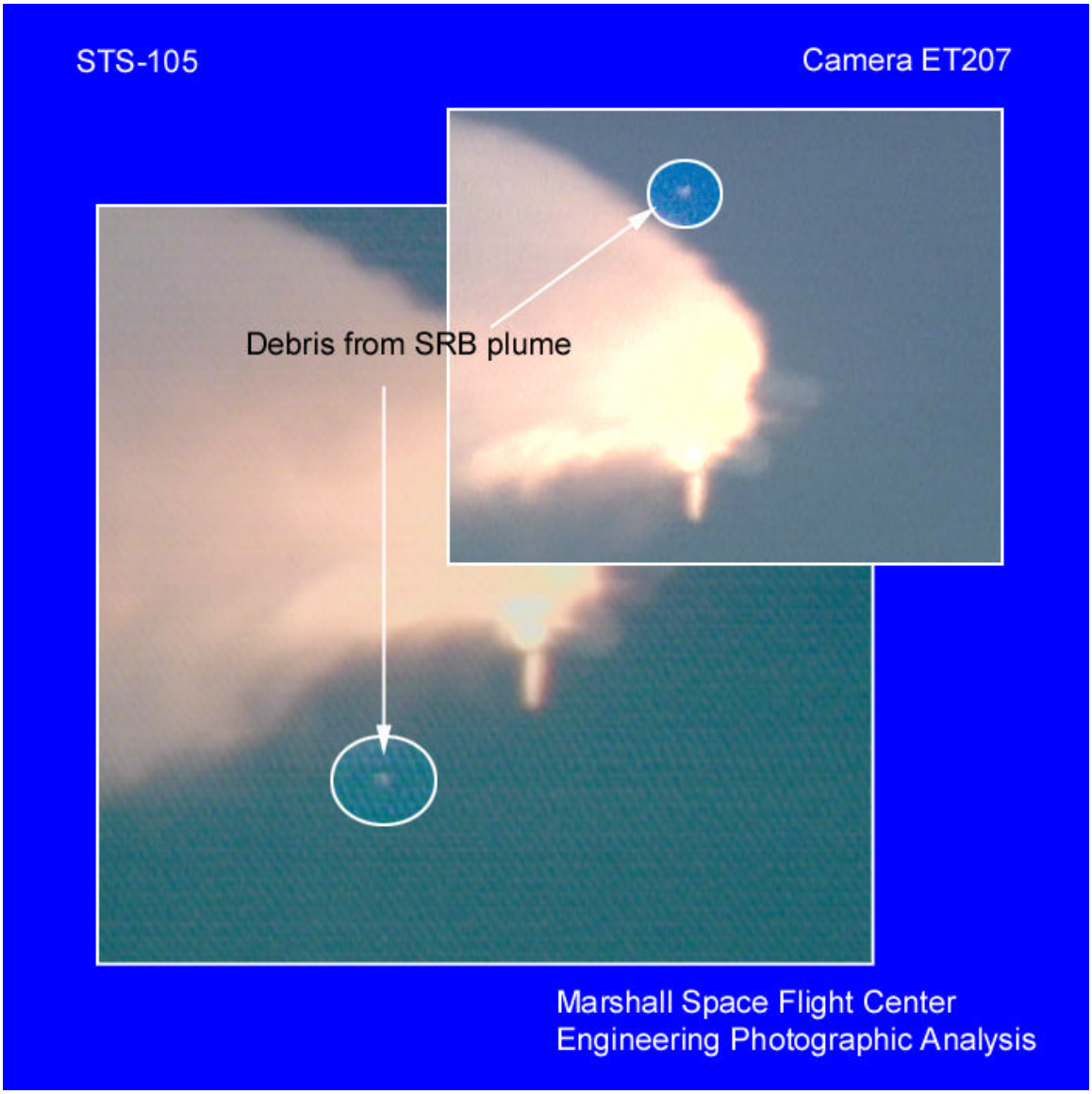


Figure 14. Debris Ejected from SRB Plume

Umbilical Well 35mm Still Camera: TPS Divots on ET Thrust Strut

Divots in the ET Thrust Strut and LOX Feedline TPS were noted. The EO-3 Separation Bolt was noted to be retracted. Charring and popcorning on the aft dome appeared nominal.

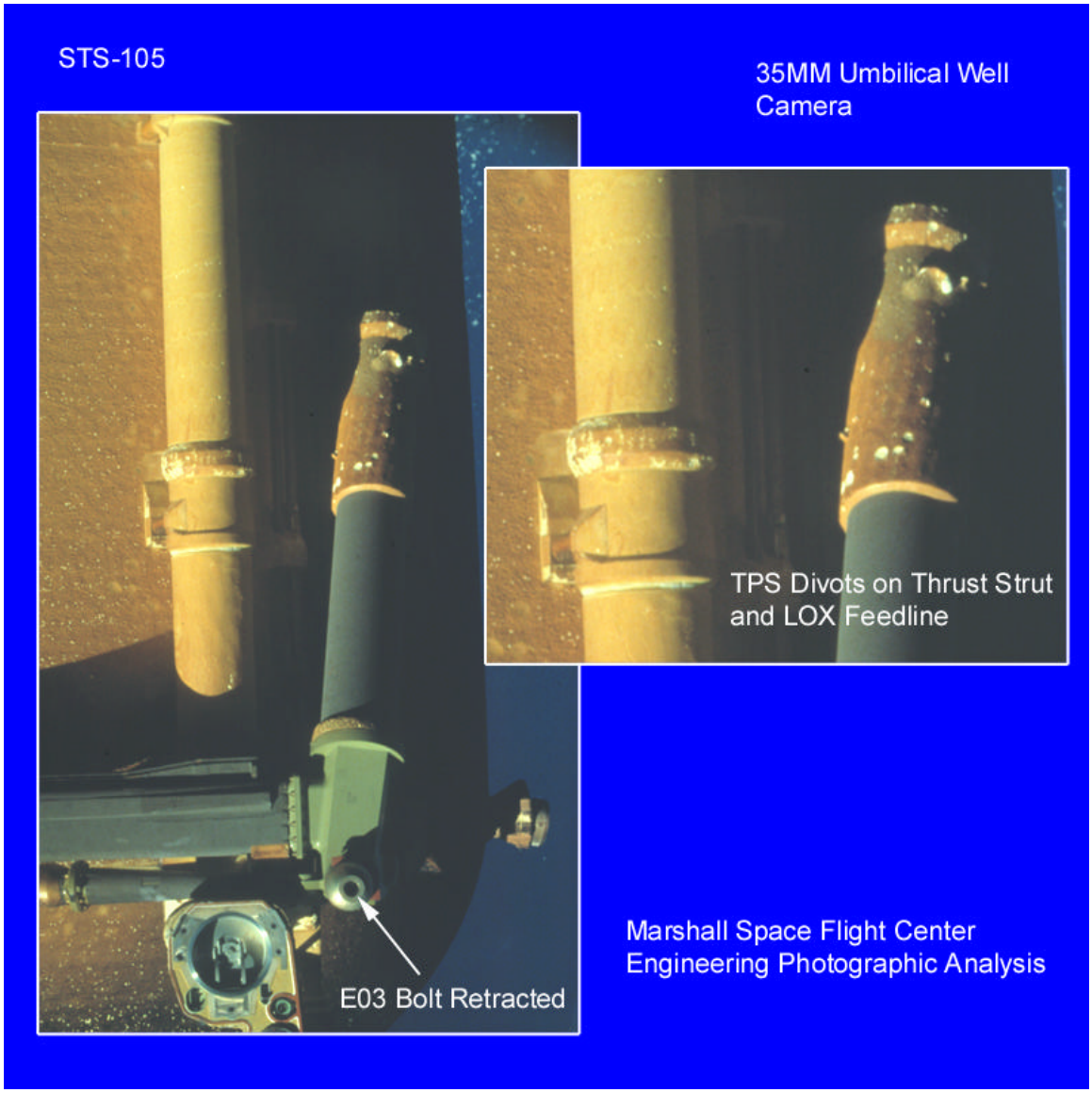


Figure 15. TPS Divots on ET Thrust Strut

Umbilical Well 35mm Still Camera: Divots on ET Intertank Acreage

Minor divoting was observed on the Intertank acreage.

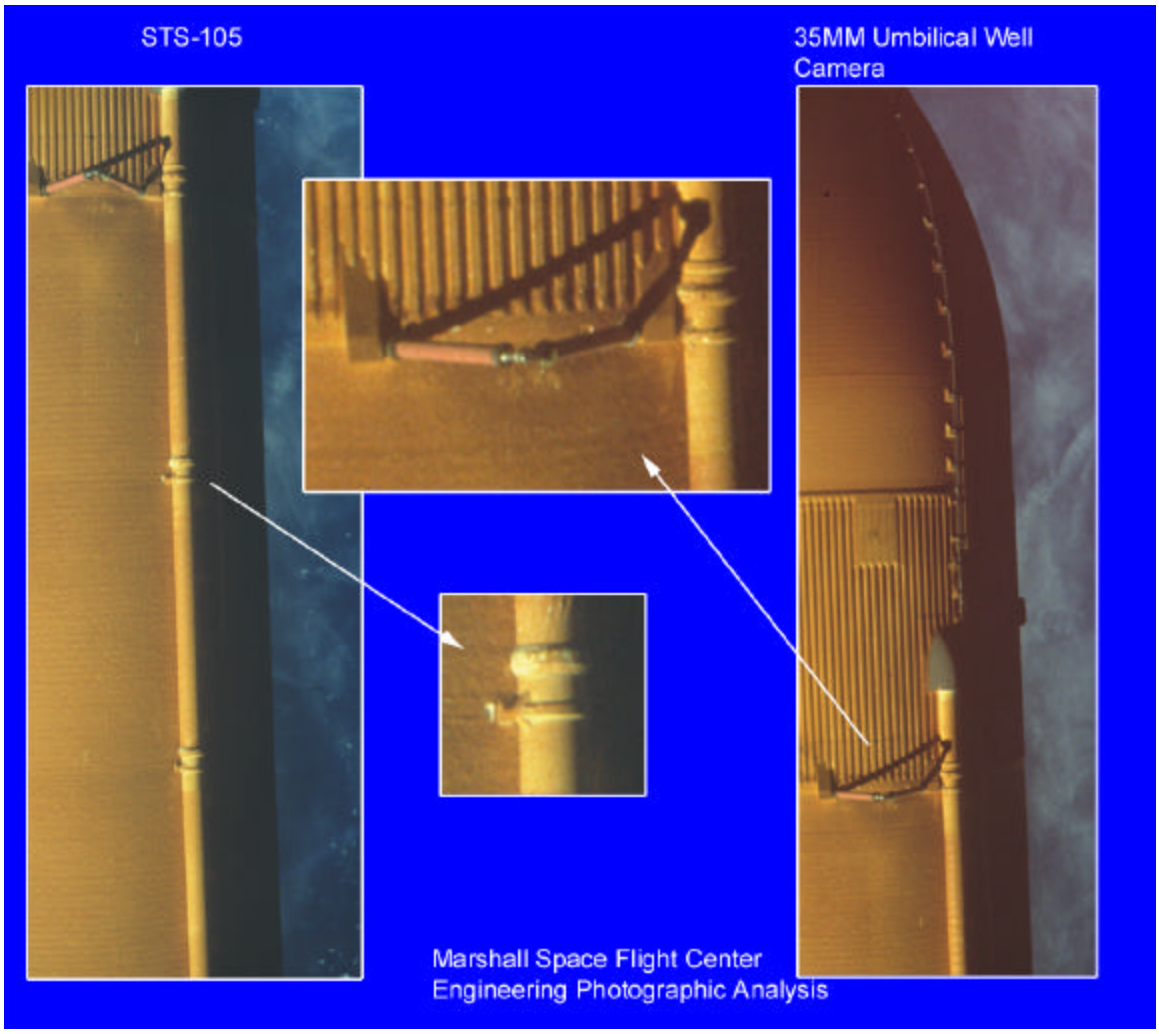


Figure 16. Divots on ET Intertank Acreage

Astronaut Hand Held Video Camera: Condition of ET after Separation

Little detail could be resolved due to image size and lighting conditions. No anomalous TPS conditions could be observed.

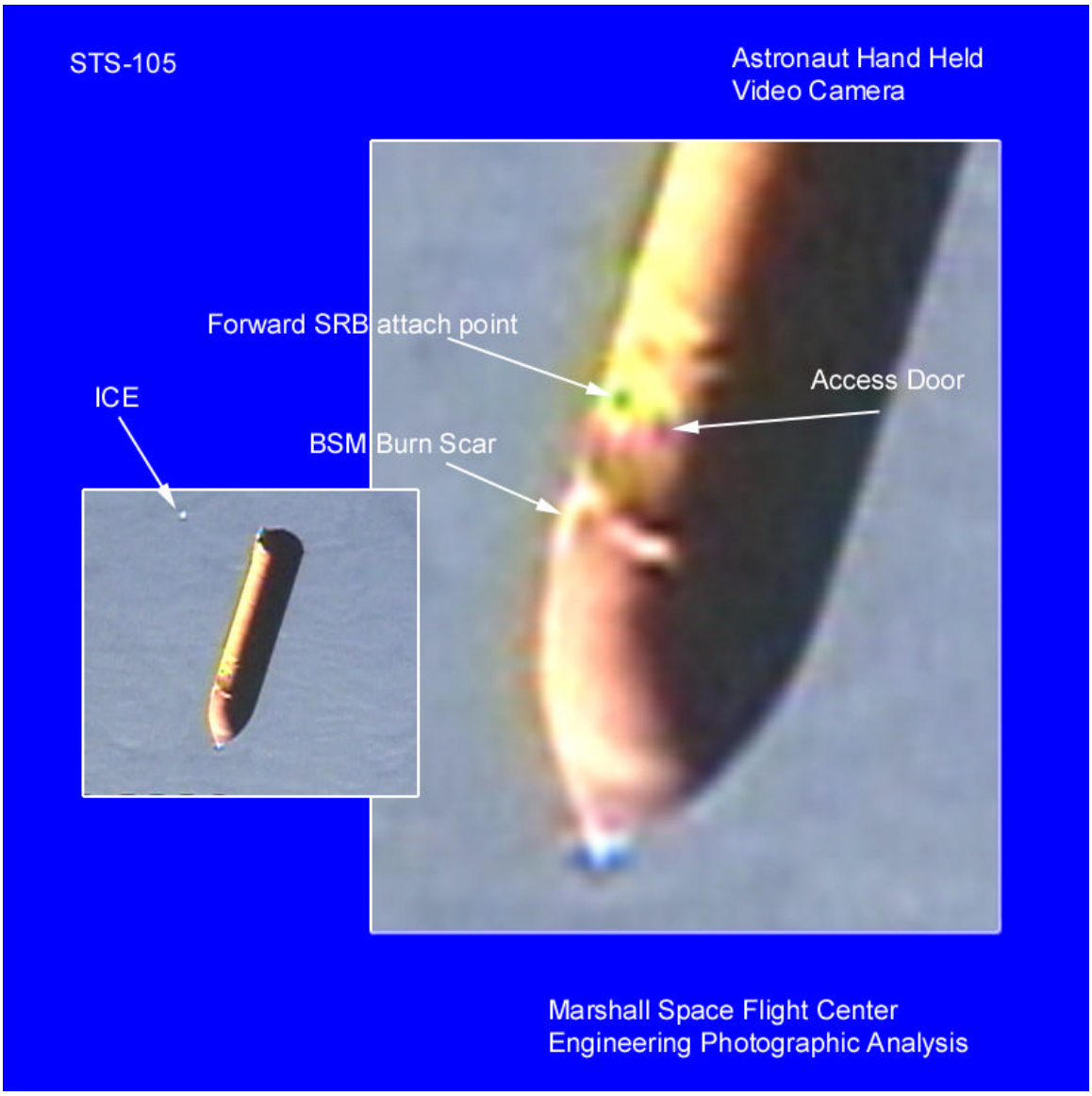


Figure 17. Condition of ET after Separation

Astronaut Hand Held 35mm Still Camera: Condition of ET after Separation

Little detail was visible due to the distance of the External Tank from the Orbiter and the lighting conditions. No obvious TPS damage was observed.

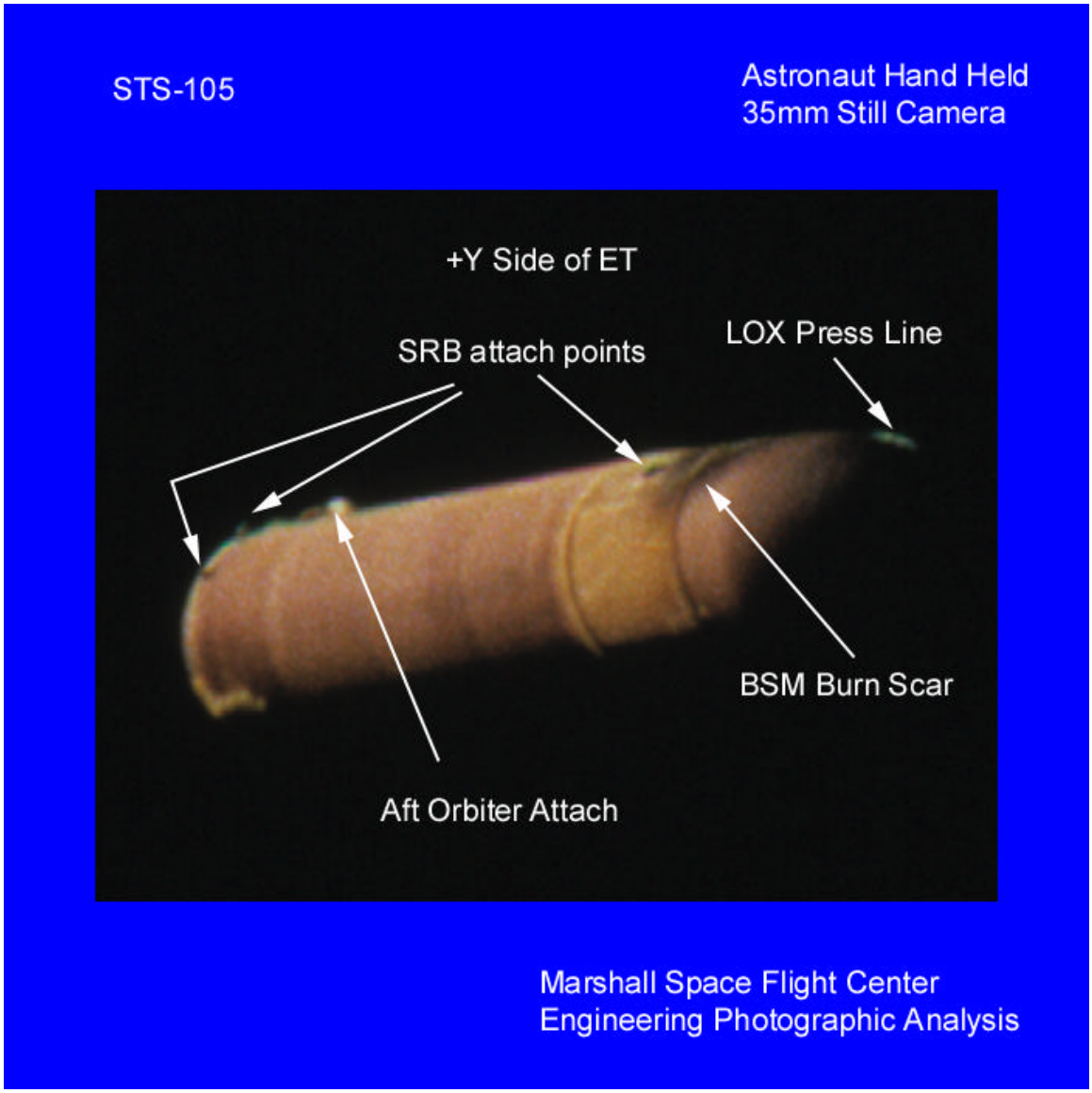


Figure 18. Condition of ET after Separation

Individual Camera Assessments:

Assessments for individual cameras are listed below. The assessments for all individual cameras including camera characteristics as noted in the Photographic Acquisition Disposition Document (PADD) for flight STS-105 may also be found on the website.

Video Camera Assessments

TV13	Linear optical distortions noted. SRB separation: 222:21:12:15.9 UTC. Debris ejected from SRB plumes prior to separation. Linear optical distortions noted after SRB separation.
TV4B	Glowing debris particles ejected from SRB plume prior to separation. Debris-induced streak in SSME plume. Condensation collar visible early in flight.
TV7B	Camera does not track vehicle as programmed.
OTV009	Typical ice/frost from 17-inch disconnects.
OTV041	High contrast and somewhat overexposed due to sun angle.
OTV04	No video available.
OTV049	Typical ice/frost from LO2 T0 umbilical. Possible chipped tile noted on right stinger pod.
OTV051	Possible chipped tile on right stinger pod.
OTV054	Typical ice/frost from 17-inch disconnects.
OTV060	Frost noted on ET Nose Cap Louvers.
OTV061	Typical debris observed falling aft of vehicle. Frost noted on ET Nose Cap louvers.
OTV063	Typical ice/frost from 17-inch disconnects.
OTV070	Typical debris observed falling aft of vehicle.
OTV071	Mach diamond formation in 3-2-1 order.
ET204	Linear optical distortions noted. Debris ejected from SRB plume near separation. IRIG timing not available.
ET207	Linear optical distortions noted. Flow recirculation noted. Condensation collar observed. Erratic tracking. IRIG timing not available. Debris particles ejected from SRB plume prior to, during, and after SRB separation.
ET212	Linear optical distortions noted. Condensation collar around vehicle observed. IRIG timing unavailable.
ET213	Linear optical distortions noted. IRIG timing not available.
HH1	(Astronaut Hand held video camera) Little detail could be resolved due to image size and lighting conditions. No anomalous TPS conditions could be observed.

Film Camera Assessments

E2	Typical debris observed falling aft of vehicle. Streaks in SSME#1 plume noted at 222:21:10:11.296, 222:21:10:12.514, 222:21:10:13.140 and 222:21:10:14.728 UTC. Streaks in SSME#3 plume noted at 222:21:10:12.078 and 222:21:10:13.380 UTC.
E3	Streak in SSME#1 plume at 222:21:10:12.514 UTC.
E6	Typical ice/frost from 17-inch disconnects.
E7	Water pipe leaking.
E8	SRB Holddown Post M2 PIC firing time at 222:21:10:14.029 UTC. Aft skirt shim appears to remain attached to the aft skirt holddown post.
E9	SRB Holddown post M1 PIC firing time at 222:21:10:14.028 UTC.
E12	SRB Holddown Post M5 PIC firing time at 222:21:10:14.027 UTC. Debris falls through field of view from top of frame. Square shaped piece of debris moves across field of view from right of frame.
E13	SRB Holddown Post M6 PIC Firing time 222:21:10:14:028 UTC. LED segment burned out on minutes display.
E15	Long rope-like debris object noted.

E17	Typical ice/frost from LO2 T0 umbilical. Tile chip noted on right stinger pod. No vibration of OMS Pod observed.
E18	Typical ice/frost from LH2 T0 umbilical. Free Hydrogen burning noted. Several chipped tiles noted on base heat shield. Cylindrical object falls through field of view from near top of TSM toward left of frame at 222:21:10:15.653 UTC.
E19	Streak in SSME#3 plume noted at 222:21:10:12:077 UTC. Chipped tile noted on right stinger pod. Nine bright areas observed on hot wall of SSME#3 nozzle.
E20	Mach diamond formation in 3-2-1 order. Four tile chips noted in left stinger pod.
E31	Typical debris observed falling aft of vehicle. Typical ice/frost from 17-inch disconnects. Apparent facility debris noted falling aft of vehicle prior to liftoff.
E33	GUCP not imaged as planned. Ice/frost from GUCP falls alongside the ET.
E34	Typical debris observed falling aft of vehicle. Unusual tile noted on forward area of left wing. Ice/frost noted falling alongside ET from GUCP separation.
E36	Typical debris observed falling aft of vehicle. Ice/Frost falling alongside ET from GUCP separation.
E40	Typical debris observed falling aft of vehicle. Frost noted on ET nose cap louvers.
E52	Typical debris observed falling aft of vehicle. Bright object observed at 222:21:10:34.309 UTC aft of right wing.
E54	Typical debris observed falling aft of vehicle. Acoustic waves visible during ascent. Image not centered in frame.
E57	Vehicle not imaged by camera.
E59	Vehicle not imaged by camera.
E63	Typical debris observed falling aft of vehicle. Mach diamond formation in 3-2-1 order.
E204	Glowing debris particles ejected from SRB plume prior to, during and after separation. Linear optical distortions noted.
E205	No Run.
E207	Glowing debris particles ejected from SRB plume prior to, during and after separation. Linear optical distortions noted. Flow recirculation noted. Orange-brown debris noted from underside of Orbiter, probably purge barrier material. Erratic tracking. Condensation collar noted. Debris noted from -Z side of vehicle, forward of SRB nozzle exit plane. Debris observed, apparently over left wing of Orbiter, just prior to SRB separation. This debris is similar to debris seen on previous missions at approximately this time. RCS motor plumes noted during separation.
E212	Glowing debris particles ejected from SRB plume after separation. Linear optical distortions noted. Condensation collar noted. Orange-brown debris observed falling aft on -Z side of vehicle. RCS motor plumes noted during SRB separation. Debris noted over right wing of Orbiter near separation.
E213	Typical debris observed falling aft of vehicle.
E220	SRB separation: 222:21:12:15.962 UTC. Erratic tracking. Condensation collar noted. Debris ejected from SRB plumes at 222:21:11:03.966 UTC.
E222	Debris-induced streaks in SSME plume. Condensation collar visible.
E223	Typical debris observed falling aft of vehicle. SRB separation: 222:21:12:15.957 UTC. Debris induced streaks in SSME plumes noted at 222:21:10:29.566 UTC and 222:21:10:29.606 UTC. Image not steady, excessive vibration and bounce. Condensation collar around vehicle noted. Numerous pieces of debris ejected from SRB plumes at 222:21:11:22.305 UTC.
E224	Typical debris observed falling aft of vehicle. Debris-induced streaks in SSME plume. Acoustic waves visible in SRB plumes at lift-off. Object, possibly debris, noted on -Z side of vehicle forward of the SRB aft attach point at 222:21:10:43.261 UTC.
FL101	(16mm Umbilical Well Camera) Clean SRB separation. The EO-2 Separation Bolt was not observed to be protruding.
UMB3	(35mm Umbilical Well still camera) TPS divots located on SRB Thrust Strut and LOX feedline noted. E03 bolt was noted as retracted. Typical popcorning of TPS acreage was observed. Minor TPS divots were observed under the bipod.

HH2 (Astronaut Hand held 35mm still camera) Little detail was visible due to the distance of the External Tank from the Orbiter and the lighting conditions. No obvious TPS damage was observed.

For further information concerning this report contact Tom Rieckhoff/TD53 at 256-544-7677 or Michael O'Farrell at 256-544-2620.

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